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THE COAL-FIELDS

OF

GREAT BRITAIN.

By the same Author.

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THE

COAL-FIELDS OF GREAT BRITAIN:

THEIR

HISTORY, STRUCTURE, AND DURATION.

WITH

NOTICES OF THE COAL-FIELDS OF OTHER PARTS OF THE WORLD.

BY

EDWARD HULL, B.A.,

OF THE GEOLOGICAL SURVEY OF GREAT BRITAIN; FELLOW OF THE GEOLOGICAL SOCIETY OF LONDON.

With Illustrations.

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TO

SIR RODERICK I. MURCHISON, D.C.L., F.R.S.,

DIRECTOR-GENERAL OF THE GEOLOGICAL SURVEYS

OF THE UNITED KINGDOM,

This little Work

IS

GRATEFULLY AND AFFECTIONATELY INSCRIBED.

PREFACE.

THE chief object of this treatise is to supply a want, which has been often expressed, of reliable information regarding the resources of our Coal-fields,—to what extent they have been already exhausted, and for what length of time the present supply can be maintained. Like many others, I was led to investigate the subject during the exciting discussions in Parliament upon the Commercial Treaty with France; and if any proof were needed of the diversity of opinion, and want of sound data upon the question of the exhaustibility of the British Coal-fields, it was abundantly afforded at that time.

It therefore appeared to me, that with the large means of information at my disposal—the Maps, Sections, and Memoirs of the Geological Survey, extending over two-thirds of the Coal-producing districts of England, the

assistance of some of my colleagues of the Geological Survey, of several of Her Majesty's Inspectors of Collieries, and of gentlemen of experience scattered throughout the country—much more definite results might be arrived at than had hitherto been published. I may also be allowed to add, that my own personal knowledge of the Coal-fields of the Central and Northern Counties is not inconsiderable, and that I have not neglected any published sources of information which were accessible.

In order to make the work more complete, several introductory chapters on the nature of the Carboniferous rocks—the character of the vegetation of the Coal-period—and the formation of Coal itself—have been introduced. Also, for purposes of comparison, I have added short sketches of the nature and extent of Coal-fields of other parts of the world, drawn from the most authentic sources.

Conscious of many defects, I am fain to hope that these pages will be found to accomplish faithfully the great object designed,—to give the public an answer to the oft-repeated question, "How long will our Coal-fields last?"

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INTRODUCTION.

The question of the exhaustibility of our coal-fields is a highly complicated one; for while an actual exhaustion is beyond all possibility, a practical and sensible failure in the supply of coal is not only possible, but certain in course of time.

The debates in Parliament have brought into prominence a subject which, from the days of Sir Robert Peel's premiership, has more or less engaged the serious consideration of public men. The opinion of the learned Dr. Buckland regarding the probable exhaustion of the British coal-fields is known to have influenced the measures of that statesman; and in the late debates on the Commercial Treaty with France, the statistical information produced by Mr. Vivian is believed to have materially influenced our legislature in favour of the measures of Government.

I refer to this debate as illustrating how diversified are the opinions entertained on this subject by some of the most eminent public men, and which are only a reflex of those of the public generally.

The want of accurate and reliable information on this subject is much felt. If legislation is to be based upon the question whether this country can, without irretrievable damage to its resources, admit of the unrestrained export of coal, it is surely of first importance that there should be accurate data to go upon; and though I admit that the question is not one which can be determined with mathematical precision, yet we may at least arrive at sufficiently approximate results, by a combination of the evidence obtained from each individual coal-field.

The first evidence of a decreasing supply will be a general rise in the price of coal: but, through the agency of railways, this will not become general until the resources of all the coal-fields shall have become developed to their full capabilities, because, where the supply shortens in one district, a corresponding impetus will be given to others now only partially opened up.

Two illustrations may be mentioned.—Many of us may live to see the southern half of the South Staffordshire coal-field exhausted, or nearly so; but while this consummation is approaching, the northern half of the same great coal-tract is far from being opened up to the extent of which it is capable. The exhaustion of the southern portion is already telling upon the northern.

The interesting and instructive coal-field of Coalbrook Dale, in Shropshire, is fast approaching extinction as a coal-producing district. There is probably not more coal than will last for a quarter of a century, at the present rate of consumption. But there is a neighbour-

ing coal-field, that of Denbighshire, capable of producing about five times its present supply. Between Brymbo collieries on the north and those of Ruabon on the south, there is a large area of virgin ground, well stored with coal, and scarcely disturbed. Other examples will be found in the following pages.

In speaking of the exhaustion of a coal-field, I do not use the term in an absolute sense. There will always be bands of coal, besides leavings, in the coal-mines, sufficient to afford a small supply to the immediate neighbourhood for domestic purposes. A coal-field may be said to be exhausted, when it is necessary to import largely from neighbouring districts for manufacturing and more general purposes. From various causes, large quantities of coal have been left in old workings, much of which it will be impossible to recover. Thus in the Leicestershire coal-field, where a bountiful Nature has left a "12-foot" coal-seam, only one half has actually been raised—the "upper," or "nether" portions being less valuable than the remainder in various parts of the field.

I have already said, that the British coal-fields can never be utterly exhausted. This is strictly true. Even disregarding the coal-beds which lie concealed beneath formations newer than those of the carboniferous period, there are, in some districts, coal-seams which are buried 6000, 8000, and perhaps 10,000 feet beneath the surface, and which can never be reached. I refer particularly to the great coal-basin of South Wales, which, as Mr. Vivian has shown, is capable of supplying the whole of England with coal;—but for, I believe, a far shorter

period than Mr. Vivian estimates it. In a future page I shall enter in greater detail into this subject; and I here content myself with stating the broad fact of the enormous depth of some of the coal-beds in the basin, on the authority of the late Sir H. T. de la Beche, and Sir W. Logan, through whose energy the magnificent geological survey of this district is now in the hands of the public. Now, without assigning in this place any theoretical limit to the depth at which coal may be worked, few will be disposed to deny that coal-seams at these depths might as well be buried beneath the waters of the Atlantic for all the probability there is of their ever being rendered available.

There are other districts, principally in the Midland counties, where the coal strata, though not themselves of any very great thickness, dip under higher formations till they reach vast depths. For instance, there is no reason to doubt that coal underlies the plain of Cheshire, between the coal-fields of Lancashire on the north, Staffordshire on the east, and Flintshire on the west; yet in order to reach the highest workable coal-seam at Northwich, it would be necessary to carry the shaft which reaches the great salt rock at least 4000 feet deeper than at present.

There are, however, very large districts in Staffordshire, Leicestershire, and Warwickshire, overspread by formations belonging to the Permian and Triassic systems, where coal may be reached at depths within 3000 or 4000 feet. In the north-eastern counties of Durham, Yorkshire, and Notts, there are also vast stores

of fuel within reach, but overspread by formations belonging to the age of the Permian and Trias. In Durham, the Magnesian Limestone, which attains there a thickness of 500 feet, has for several years been penetrated in various places down to the underlying coal; and the same formation in its southerly extension into Yorkshire and Nottinghamshire, bids fair to become a coal-producing district of large extent and capacity. One of the deepest mines in England, that of Shireoak, near Worksop, belonging to the Duke of Newcastle, is situated in the Magnesian Limestone; and after obstacles of no ordinary kind had been triumphantly surmounted, was carried down into the long-wished-for coal-seam, at a depth of 510 yards.

The depth of many coal-shafts in the north of England is very great. At Ince, near Wigan, the "Cannel" seam is reached by means of two "lifts," at a depth of 600 yards.* Pendleton colliery, near Manchester, is 536 yards deep; that of Dukenfield, Cheshire, 686 yards. The Monkwearmouth pit, near Sunderland, has a depth of 530 yards: and collieries with shafts between 400 and 500 are not uncommon in the coal-fields of Lancashire, Yorkshire, and Durham.

Notwithstanding, however, all that art and industry can invent to facilitate mining at great depths,—notwithstanding the increased powers of the machinery and improvements in ventilation, the employment of flat wire ropes, the substitution of steel for wrought iron, and the use of two or more "lifts" or stages, at

* Appendix A. p. 175.

intervals from the bottom of the mine,—we must ultimately reach a depth at which the temperature will be so high as to prohibit inexorably mining operations. What that depth may be I shall discuss in a future chapter: in the meanwhile, let us review briefly the progressive course of coal-mining from its infancy to the present time.

PART I.

CHAPTER I.

FRAGMENTS IN THE HISTORY OF COAL-MINING.

THE first attempts at coal-mining are enveloped in obscurity; but even from the chronicles of those days, when nothing was thought worth recording save the accession of a prince, the feuds of neighbouring states, and the details of a battle, enough has been incidentally noted to enable us to trace back the art of coal-mining to very early times.

Its beginning was sufficiently humble. Its nature and properties being little understood, there was nothing in the outcropping of a black substance along the sides of a hill or the banks of a brook to arrest attention; and it is therefore not improbable that from the earliest periods—at any rate from the time in which implements and weapons of metal replaced those of flint—fossil fuel may have been employed for smelting purposes. Fortunately on this point we are not left altogether to conjecture, as I shall have occasion to show presently.

Like many other treasures of Nature, the use of coal did not become general until its necessity had become

paramount. While in the days of Anglo-Saxon and Anglo-Norman art, and those which immediately succeeded, the plains of England were overspread with almost continuous forests, growing, as in Staffordshire and Lancashire, frequently in dense luxuriance over the mineralized forests of geologic times, and while these forests readily yielded an abundance of fuel for all the purposes of the times, it was both unnecessary and improbable that the labour and risk of mining should become general. The precious mineral was reserved for a generation to whose very existence it is almost a necessity; a generation that, without its aid, could scarcely (as far as we can see) have arrived at the position in art, industry, and navigation, which it has attained in the nineteenth century.

I must now ask my reader to accompany me through a few of those details in the history of coal-mining which I have been able to collect. I do not profess to have exhausted the subject; for the more I have entered into it, the more am I satisfied that much remains to reward the industry of the antiquarian. The notices we find are like stepping-stones for crossing a river; sometimes they are large, copious, and closely placed, at other times wide apart, so that we have to make a leap perhaps over several centuries at a time; but I have no doubt further researches will enable us to add to the numbers of the stone-steps, so as to lessen the gaps, if we cannot hope to make a continuous road from the shore of the past to that on which we stand.

It is scarcely necessary to observe, that the frequent

references to coal in the Sacred Scriptures cannot be considered as pointing to that mineral as at present understood. The original word doubtless means charcoal, which, like the Latin term, may be employed to designate fuel of both kinds. I should not, however, be so confident that coal itself was not sometimes intended, if there was any certainty of its existence as a product of the Holy Land or Arabia; but as far as I am aware there is no mention by any traveller of this mineral occurring amongst the Nummulite limestones, the red sandstones, or basaltic lava-floes of these countries. Its nearest position is perhaps on the shores of the Black Sea and Bosphorus.

Period before Christ.—Theophrastus, a Greek author who lived about 238 years before the Christian era, describes in brief but determinate language, the nature, uses, and source of coal. It is a sufficient proof of this mineral being intended, that the description applies accurately to it, and to no other. He says: "They call those fossil substances (λιθὺς ἄνθρακας) anthracite (or coal), and when they are broken up for use, are of an earthy character (γεώδεις); nevertheless they inflame and burn even like charcoal (καθάπερ οἱ ἄνθρακης), and are used by the smiths." He adds, that the coal is found along with amber and other substances in Liguria, and in Elis on the road to Olympias over the mountains.*

* It is scarcely necessary to give the original passage of which the above is a literal translation, and varies only slightly from that of Mr. John Hill, who edited an edition of the "History of Stones" in 1746. Pennant also notices the passage, and does not hesitate to refer it to coal.

There are several other passages in the same work descriptive of combustible minerals, but described in such vague language that it is impossible to identify them. The passage above quoted is, it appears to me, sufficient, and its value would scarcely be strengthened by the addition of a score of others which might be applied to as many different substances.*

The passage in Pliny † is of little service, though sometimes quoted as referring to coal. Speaking of a certain earth (Chia terra), he merely says of it that "Bitumini simillima est ampelitis." Theophrastus, in speaking of this stone, says: "There is a certain earth in Cilicia, which is heated and becomes glutinous. With this they smear the vines (as a protection) against worms." Strabo reiterates the above description—in all probability only quoting it.

Ancient Britons.—It might scarcely be credited, were it not established on incontestable evidence, that there were coal mines amongst those savage clans and roving barbarians, such as we are generally taught to consider the Britons of prehistoric times. The discovery of a flint-axe stuck into a bed of coal exposed to-day in Monmouthshire is a fact which, like the occurrence of a solitary fragment of a plant in a very ancient rock, proves a great deal more than appears at first sight. If we accept the theory, that flint-weapons were the earliest representation of three stages of civilization, of which bronze implements were the second, and iron implements

* See also the same author in "Περι Λιθων." Art. 49.

† Nat. Hist., lib. xxxv. 16.

the third, this discovery carries us back to a very early period, antecedent to the invasion of the Romans.

I am persuaded this is not a solitary case, though I know of none strictly parallel. Near Stanley in Derbyshire, some years since, while some miners were engaged in driving a heading through the "Kilburn coal," they broke into some very old excavations, in which they found axes or picks formed out of solid oak. The implements were entirely destitute of metal, and were cut out from one solid piece of timber. It is hard to imagine the use of such an instrument where iron was known; while it is also difficult to conjecture how an axe of this kind could have been formed without the assistance of iron. The neighbourhood of these old workings, abounds in iron-ore, several beds of clay iron-stone occurring both above and below the Kilburn coal. If the use of these ores had been known, it is scarcely to be supposed that the miners would have made use of picks formed entirely of oak. Implements which appear to have belonged to an equally early period are stated to have been found in old coal-workings near Ashby de la Zouch, consisting of stone hammer-heads, wedges of flint, as also wheels of solid wood.*

Whittaker states that there is indubitable evidence from the discoveries at Castle-Field, near Manchester, that the Britons had made use of coal in that neighbourhood. He refers to the existence of fragments of coal in the beds of sand *under* the Roman road, and in a pit a few feet deep contiguous thereto.† But I very much doubt

* Mammat's "Geological Facts."

† "History of Manchester," vol. i., p. 302 (1771).

the value of such evidence. Those acquainted with the Drift, or Post-pliocene deposits of Lancashire and Cheshire, know that drifted fragments of coal are extremely plentiful therein; and there is strong probability that those upon which he dilates so enthusiastically were carried to their beds in the sand long even before the time of the *Aborigines* of Britain; but not by the hand of man.

Romans in Britain.—That the Romans were acquainted with the use of coal during their occupation of Britain is highly probable, both from what we know of the character of the race and from circumstantial evidence. They had stations in many places close to the out-crop of valuable coal-seams, and cinders have been found amongst the ruins of Roman towns and villas. I may here mention a case which has always appeared to me as probably referable to this period. Wigan in Lancashire was a Roman station. Not far to the north of that town, a bed of coal—one of the most valuable in Lancashire, and known as the "Arley Mine,"—out-crops along the banks of the river Douglas. Not long since, while driving a tunnel to divert the course of the river, this coal-seam of 6 feet in thickness was found to have been mined in a manner hitherto altogether unknown. It was found to have been excavated into a series of polygonal chambers, with vertical walls opening into each other by short passages, and on the whole presenting on a ground-plan something of the appearance of a honeycomb. The chambers were stated to be regular both in size and form over an area of at least 100 yards in one direction, and were altogether different from

anything within the experience of the miners of the district. Local tradition ascribed these excavations to the Danes, though I could not discover upon what grounds. We should probably be nearer the truth in assigning them to the Romans during their sojourn in these parts. There is something in the symmetrical arrangement and regularity of the works peculiarly Roman, reminding one of their tesselated pavements, or the ground plans of their baths and villas, in which symmetry of form appears to be the guiding spirit. It would, however, have been more satisfactory had the evidence rested on the discovery of works of art within the excavations. But it is time to return from this digression to the more sure word of history.

If Whittaker, the historian of Manchester, has been unsuccessful, in my opinion at least, in establishing upon satisfactory evidence the use of coal by the Ancient Britons, he has been more fortunate in showing that fossil fuel from the Lancashire coal-fields was burnt by their successors, the Romans. Castle-Field—an original settlement of the Britons—was afterwards possessed by the Romans under the name of Mancunium. In the course of time it has slightly changed its name, and developed into the metropolis of the northern counties of England. Amongst other Roman remains turned up about a century ago, cinders and scoriæ were discovered in several places, as well as the "actual refuse of some considerable coal-fire."*

The same author also relates, that in the West Riding

* "History of Manchester," vol. i., p. 301 (1771).

of Yorkshire, near North Brierley, a quantity of Roman coins, the very best indices for dates, were found "carefully reposited" amid many beds of coal-cinders heaped up in the adjacent fields.*

Assuming from the general consideration of the case that coal was not unknown to the Romans—though they do not appear to have invented a name for it while in Britain, and it was probably used more from curiosity than from necessity—we enter upon the Anglo-Saxon period, in which there is documentary evidence of the use of pit-coal for domestic purposes.

Anglo-Saxon Period.—Britton, in his description of Peterborough Cathedral, renders into modern English the following paragraph taken from the Saxon Chronicle of the Abbey of Peterborough:—"About this time (A.D. 852) the Abbot Ceolred let to hand the land of Sempringham to Wulfred, who was to send each year to the monastery '60 loads of wood, 12 loads of coal, 6 loads of peat, 2 tuns full of fine ale, 2 neats' carcases, 600 loaves, and 10 kilderkins of Welsh ale, 1 horse also each year, and 30 shillings, and one night's entertainment.'"† How Wulfred was to send the provident abbot "one night's entertainment" it is not necessary for our purpose to inquire; but this statement of the chronicler is highly valuable as establishing the fact that coal was at this early period an article of household consumption. It may also have been made use of by the monks, who were the artificers and craftsmen of their times, in the manufacture of metal-work for the churches and monasteries.

* "History of Manchester," vol. i. p. 303. Appendix B. p. 176.
† "Cathedral Antiquities," vol. v.

In connection with this period, it is matter for discussion whether our term "coal," which is evidently identical with the German "kohle," has been derived from our Saxon ancestors, or whether on the other hand the Germans have derived it from us. It is probable the term was in general use before the invasion of the Normans, otherwise the French or Latin name would in all probability have been adopted. The Saxon name *col* (now coal) appears to have superseded the old British name *glo*, and if introduced into Britain at the colonization of the country by the German tribes, it is in favour of the supposition, that the art of coal-mining was practised in Europe during the first centuries of the Christian era.*

* I have been favoured with the following note on the derivation of the word Coal by my relative, Mr. William J. Leacock, which I give entire:—

"There are only five copies extant of the original Saxon Chronicle, of which four are in the British Museum. The original Anglo-Saxon words used in reference to Wulfred's rent to the Abbot of Peterborough are—'anꝺ ꞇpælꝼ ꝼoðuꞃ ꞅꞃæꝼan,' *i. e.*, in modern English letters, 'and twælf rothur græfan.' Bosworth, in his A. S. Dictionary, gives under Græfe, an; m. Coal: Carbo fossilis. Chr. 852: (*i. e.*, the above passage), so that this seems to be the only passage in which the term is used. No derivation is given, and I can find no parallel in the Dutch or German; but perhaps as we have Anglo-Saxon 'Greaf or Graf;' Dutch the same, German 'Grab,' and so through all the northern languages, for a trench or 'grave,' it simply means the 'dug-up' earth.

"I find, however, in the A. S. Dictionary, 'Col. plur. cola, colu. [T[illegible] *i.e.* Teiresia *hôal*, Dut. hool.] Coal, carbo: with reference to P[illegible] 13 and 139. 11, *i. e.*, the Psalms, by Spelman, London, 1640, the [illegible]sion of the Vulgate being used.'

"There is also, Gled, Gloed, plur: with many parallels in the northern languages, meaning a burning coal, coal, fire; carbo. used in Ps. 17. 14, &c.

["In

Anglo-Norman Period.—It is matter for surprise, as well as regret, that in the Great Survey of England carried out by William the Conqueror, and recorded in that most matter-of-fact book, the Domesday Book, no instructions were delivered to the commissioners for inquiring into the extent and value of the mineral property of the central and northern counties. They appear to have confined their investigations entirely to the extent, rights, and ownership of the surface land, together with the classification of the inhabitants; but throughout the counties of York, Lancashire, Derby, and Nottingham, abounding in coal and other minerals, no mention whatever is made of these latter sources of wealth.

In order to test this point, I turned to the page relating to Chellaston in Derbyshire, where a most valuable bed of gypsum, or alabaster, underlies a large extent of surface at no great depth, and crops out as a solid bed ten or twelve feet in thickness. This mineral (which we know to have been worked centuries ago) could not even at that time have been undiscovered, for the ploughshare scrapes its surface in many places,

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"In Somers' A. S. Dict. the word *Græfa* is not to be found; but *Græf*, which means a grove as well as a grave. He gives 'Col. carbo., a coal to burn;' but says nothing about derivation.

"The following is Richardson's etymological account of the word 'Coal.' He says it is 'of unsettled etymology. A S. *Col*: German and Dutch *Kole*: Sw. *Kol.*' Vossius derives from the Greek, χαλεος pro χηλεος, Ignis epitheton. Wachter from χηλοειν, comburere. Ure seems to decide for the Sw. *Quilla*, Westro-Goth *Kylla*, accendere ignem (to kindle a fire).

and it may well be supposed to have been a source of wealth to the owner. Yet there is no mention made of the mineral value of the property in the "Dom Boc." Even the lead mines of Derbyshire, known to have been worked by the Romans, are unnoticed, and therefore we need not be surprised that coal receives no mention.

However, in the Boldon Book, containing the census of portions of the northern counties, and published in the reign of Henry II., we find at least two references to coal in connection with smiths' work. Faber, an inhabitant of Vernouth, and a person of the same name dwelling in Seggeefeld, are described as "finding coals" (carbones invenit).* I think this passage cannot be considered as referring to charcoal. The use of the word *invenit* would be inapplicable to the burning or producing of charcoal from wood, and evidently refers to something which required discovery. It is also not impossible that the Faber belonging to both localities may have been of the same family. The census of Seggefeeld follows that of Vernouth almost immediately, and the places were probably contiguous. Now here we possibly have an intimation of the early habit of the profession of coal-mining running in families, a

* Inquisitio de consuetudinis, et reditibus totius Ep'atus Dunelmensis, Anno 1183. The difficulty of reading this work, which, like the Domesday Book, is full of abbreviations and elliptical expressions, is great; as examples I quote the passages above alluded to:—"Vernouth. Faber xii. acr' ꝑ ferramentꝭ caruc' & carbones qm' invenit." "Faber, 1 bovat. ꝑ ferrametꝭ caruc'. que fac'. & carbon' invenit."—See Appendix C. p. 176.

habit which at any rate exists in full force in the present day. In the manufacturing and mining counties the factory operatives and colliers form distinct classes, separated by habits, and sometimes political feeling: a similar distinction of class may be observed in other districts where the inhabitants are divided between mining and agriculture, the pursuits of each being hereditary and traditional. Can it be possible that these habits were in operation seven hundred years ago?

The Latins had an old proverb, quoted amongst many others by Phædrus, "Carbonem, ut aiunt, pro thesauro invenimus." This has been considered as referring to charcoal; but it appears to me under this supposition to lose all its significancy. The same objection may be urged to this interpretation as has been stated in reference to the passage in the Boldon Book—for the same expression is used in both. "Finding" a lump of coal instead of treasure has some meaning in it, but the finding of a piece of charcoal under similar circumstances appears utterly unintelligible.

The year 1259 is memorable in the annals of coal-mining. Hitherto the mineral had not been recognised by authority or in any public document; but in that year King Henry III. granted a charter to the freemen of Newcastle-on-Tyne for liberty to dig coals. Under the term "sea-coal" a considerable export trade was established with London, and it speedily became an article of consumption amongst the various manufacturers of the metropolis. But its popularity was short-lived. An impression became general that the smoke

arising therefrom contaminated the atmosphere, and was injurious to the public health. Years of experience has proved the fallácy of the imputation; but in 1306 the outcry became so general that the Lords and Commons in Parliament assembled presented a petition to King Edward I., who issued a proclamation forbidding the use of the offending fuel, and authorizing the destruction of the furnaces and kilns of all who should persist in using it. This was the year before the monarch's death, and the year which saw the overthrow of his life-long attempts upon the throne of Scotland, through the intrepidity of Robert the Bruce. But the proclamation against coal was as abortive as the endeavour to conquer the patriotism of the Scots. Prejudice gradually gave way as the value of the fossil fuel became better known, and from that time downwards its use became more extended; and it is very probable that throughout the 14th and 15th centuries coal was extracted near the outcrop of the beds over most if not all of the coal-fields of Britain and Ireland. Historical records are still extant from which we learn that collieries were opened during the 14th century in various parts of Yorkshire, Durham, and Northumberland. (Appendix D.)

The difficulties under which mining operations were carried on before the invention of the steam-engine, and more particularly of the "Davy lamp," must have been very great. An anonymous writer in the "Builder" states, that in many mines the only alternative the mediæval miner had to pitch darkness was the phos-

phorescent gleam from dried fish.* Those who wish to understand the art of mining as it was carried on at this period will find their curiosity amply gratified by turning over the pages of Agricola's work on this subject. The author, who wrote in the middle of the 16th century, has illustrated the various processes by a profusion of quaint drawings on a large scale. The horse-gin, which survives to the present day in many districts, was the engine chiefly employed both for lifting the coal and for getting rid of the water. This latter object was also sometimes effected by means of pumps turned by windmills, or through tunnels driven with great labour to an outlet at a lower level.

Pennant, in his account of the collieries of Flintshire, states that there is documentary evidence to show that the coal-seams of Mostyn were worked in the time of Edward I.; and in the 17th century, Dublin and the eastern parts of Ireland were supplied from this district.†

In the year 1600, or thereabouts, coal was worked at Bedworth in Warwickshire, as we learn from Camden, who describes the process, and says that the miners assured him that large *toads* had been found in the solid coal.‡ In this century also the mineral treasures of the

* See Appendix E. p. 179.

† Tour in Wales, vol. i. (1784).

‡ Camden's Britannia. Gough's edit., vol. ii., p. 464. This belief amongst miners of the existence of live toads in coal is very extraordinary, and is almost coextensive with the art. I was assured by a miner in Lancashire, near Ormskirk, that a toad had been brought up in a piece of coal from a mine thirty-six yards in depth, which immediately revived on reaching the surface!

bishoprick of Durham were well known; and early in the 17th century the cannel-coal of Lancashire was used, not only by the poor for candles, but was manufactured into various articles of ornament or use. Camden, in speaking of the discovery of this most valuable description of coal at Haigh, near Wigan, says—"This neighbourhood abounds with that fine species of coal called *canal* or *candle*. It is curious and valuable, and besides yielding a clear flame when burnt, and therefore used by the poor as candles, is wrought into candlesticks, plates, boxes, &c., and takes a fine polish like black marble.*

That coal was worked in Ireland at least as early as the beginning of the 16th century, and possibly much earlier, may be inferred from the following account given by Hamilton in his "Letters on the Coast of Antrim." He relates that in 1770 the miners of Ballycastle, in pushing forward an adit towards a bed of coal in an unexplored part of the coal-field, unexpectedly broke into a narrow passage, which proved to have been carried several hundred yards to a bed of coal, and then branched off into chambers. Pillars had been left at proper distances. Some remains of tools and baskets were found, which speedily crumbled to pieces. Those who are aware how the accounts of mining operations are handed down through several generations will readily admit that the old works here mentioned, and of which all local tradition had been lost, must have been carried on at least a century and a half before the period

*"Britannia," vol. iii., p. 390.

when they were afterwards discovered, which would throw back the date nearly to the beginning of the 16th century.

In Scotland the coal-seams of the Lothians and Fife-shire were probably worked at a very early period. Agricola, and after him Camden, mentions that in his time there existed in the latter county old coal-pits, filled with water, and surrounded by mounds of refuse called *coal-heughs;* and he adds that "many of the beds of coal have been on fire for centuries, and the heat still continues to melt the snow on the surface."* These old coal-works would appear to have been at least as old as the 15th century.

Campbell, in his "Political Survey of Britain," published in 1774,† gives us some interesting details of the coal-trade in his time. He states, that although coal was employed in manufactures for several hundred years, it did not come into general use till the reign of Charles I., and was then sold for seventeen shillings a chaldron. In 1670, about 200,000 chaldrons, and at the Revolution (1690) upwards of 300,000, and in the reign of George III. (1760) double that quantity, was annually consumed in Britain. He adds, "There is little room to be alarmed from the apprehension of their (the mines) being exhausted, as the present works are capable of supplying us for a long series of years, and there are many other mines ready to be opened when any of these shall fail,"—a piece of information

* Camden's Britannia, vol. iv., p. 114. This elaborate work was published in 1607.

† Vol. ii., p. 30.

which must have been exceedingly consolatory to those of the last generation, but not so assuring to us who have lived to see the annual consumption of nearly 70 millions of tons.

Sir John Clerk, in a letter to a friend, written in 1739, gives an interesting account of the collieries of Whitehaven.* The coal-beds even at that time were worked far under the sea, so that, as the writer observes, Sir James' riches in part swim over his head, for ships pass daily above the very ground where his colliers work. The coals were drawn up by an engine worked by two horses, which went their circuits at full trot every eight hours, and three changes were employed every twenty-four hours. Sir John Clerk then proceeds to give a long and minute account of the quantity of coal raised, its cost, and how much the proprietor cleared after paying all expenses, which amounted to the very moderate figure of 600*l.* a year, or thereabout. The writer also states that the upper coal-seams were much exhausted near the sea, but that untouched treasures lay below.

We have now reached the margin of a new epoch in coal-mining, marked by the discovery of the safety-lamp by Sir Humphry Davy, and of the steam-engine by Watt. While the latter invention opened up a thousand new channels for the employment of coal, and at the same time gave the power of raising this mineral

* These collieries belonged to Sir James Lowther, who was held in high estimation by the people, his death being looked forward to as a public calamity. Camden, vol. iii., p. 434. Gough's Edit.

from great depths, the former enabled the miner to light his way through those dark caverns surrounded by inflammable gases with comparative safety. As was once truthfully and grandly said by Robert Stephenson:—"We are living in an age when the pent-up rays of that sun which shone upon the great Carboniferous forests of past ages are being liberated to set in motion our mills and factories, to carry us with great rapidity over the earth's surface, and to propel our fleets, regardless of wind and tide, with unerring regularity over the ocean." Alas! that so great and good a man did not survive to see that greatest triumph of naval architecture which has just returned to our shores. It is significant that the largest ship and the longest bridge the world has ever seen should have been completed in the same year, while it was not the will of Providence that their projectors should themselves witness their completion. We may safely aver, that but for the invention of the steam-engine and the produce of our coal-fields, these great works would never have been projected.

We have now carried down the history to our own times.

The average quantity of coal raised annually in Great Britain is 67 millions of tons, which is at least three times greater than the combined produce of all the remaining coal-fields of the world. This will appear from the following synopsis.

Annual Production of Coal in various Countries.

	Tons.
Great Britain and Ireland	65,887,900*
United States of America	5,000,000†
British Possessions of America	1,500,000‡
Belgium	8,409,330‡
France	7,740,317‡
Prussia and Austria	4,200,000§
Saxony	1,000,000
Russia and other European States	1,000,000‖
Japan, China, Borneo, Australia, &c. ..	2,000,000‖
Total produce of the world	96,737,547

It thus appears that the total quantity of coal raised over the whole globe is about 97 millions of tons, of which the produce of Great Britain is more than two-thirds, and would be sufficient to girdle the earth at the equator with a belt of 3 feet in thickness, and nearly 5 feet in width.

Now if we recollect that the coal-fields of the United States of America are nearly fifty times larger than those of Great Britain, we may form some conception of the enormous drain to which, in comparison with that country, the mineral resources of our little island are now being subjected.¶

* "Mineral Statistics of Great Britain," by Mr. R. Hunt, 1858.
† Taylor 's "Statistics of Coal," 1855.
‡ For the year 1856. Appendix E.
§ Encyclopædia Brit., 8th Edit.
‖ Estimated.
¶ See Part iii. Chap. 4.

CHAPTER II.

FORMATION OF COAL.

That coal is of vegetable origin, is demonstrated not only by its microscopic structure, its combustible properties, but also by its position in the strata, and the fossil plants with which it is always associated. There are at least two theories, each having its advocates, to account for the formation of coal: the first, which would assign its origin to the drifting of vegetable matter by rivers and floods into estuaries and shallow seas, where becoming water-logged it formed a bed or stratum along the bottom, and was entombed by the overspread of sediment; the second, which refers its origin to the growths of successive forests in the positions, and over the areas now occupied by the seams of coal themselves.*

Without denying the probability that some exceptional beds of coal have been accumulated by drifting, and believing that drifted plants and stems of trees are of frequent occurrence in the sandstones and other strata of the Coal-measures, yet the second theory,—that of the growth of the plant s*in situ*,—appears so much superior to the former in explaining the complicated phenomena which present themselves, that I feel constrained to adopt it here.

* The arguments and difficulties on both sides of the question are very fairly stated by Mr. Jukes, in his "Memoir on the South Staffordshire Coal-field." Second Edit.

It will, however, be more intelligible, if the reader becomes in some degree familiar with a few of the leading members of that luxuriant flora which flourished in the Carboniferous period.

That we have only a fragmentary wreck of the plants of this period must be evident, for although vegetation attained a vigour which has never before or since been equalled, yet the number of species of coal-plants as yet determined is only about 1-20th of that now growing over Europe alone. The number of species noticed by the great fossil-botanist Brongniart was 500, which are classified as follows :*—

Thallogens	6	species
Acrogens	346	„
Gymnosperms . . .	135	„
Doubtful	13	„

Unger has raised the number to 683; but when we recollect that this includes not only the plants of Europe but of North America, it shows how much is lost to us of the vegetable productions of this period.

The perishable nature of plants under moisture, or water, is the principal cause of the fewness of the species preserved. For instance, there is every probability that there were grasses, mosses, and sedges, but of these we have scarcely a trace. It is probable, however, that individuals of a few species predominated very largely, as is the case now in our pine forests; or the great cypress swamps at the mouth of the Mississippi.

* "Histoire des Végétaux Fossiles." (Appendix F.)

Dr. Lindley, by a very interesting experiment, appears to have arrived at a clue to account for the large preponderance of certain classes of plants amongst those which have been preserved. By immersing in cold water for two years a large number of plants, as nearly as possible representatives of those of the Coal-measures, he obtained the following results.—He found that the Dicotyledonous plants are in general incapable of resisting decomposition when immersed for two years, with the exception of the Coniferæ. 2ndly, That Monocotyledonous plants are less liable to decomposition, but that grasses and sedges perish rapidly. 3rdly, That fungi, mosses, and equisetums disappear, while ferns have a great power of endurance, the effect of immersion being only *to destroy all traces of fructification;* a satisfactory reason why fossil-ferns scarcely ever present this portion of their structure, though the fronds themselves occur in great numbers, and in admirable preservation.*

There appears to have been a uniformity in the vegetation of the coal-period, to which there is now no parallel. The same genera, and most of the same species, ranged throughout the whole of Europe, and of North America from the Arctic regions as far south as the 30th parallel of North latitude; and this uniformity of vegetation is continued vertically, for we find the same species ranging throughout the whole series of strata, sometimes amounting to a thickness of 10,000 feet.

But perhaps the most inexplicable phenomenon in connexion with this subject is the occurrence of coal and

* Lindley and Hutton: "Fossil Flora," vol. iii.

Carboniferous plants in the Arctic regions. Reasoning from analogy we could never have supposed that in latitudes now subject to the severest frosts throughout the greater part of the year, and even deprived of light for a long period, a vegetation could have flourished allied to that of the tropics, or at least to that of the warmer temperate zones of the present day. But, in truth, the period of the coal-formation was entirely unique; it was never forestalled, and has never been repeated; and of some of the most important coal plants, as *Sigillaria* and *Lepidodendron*, there are no living representatives. The general opinion of the highest authorities,* appears to be that the climate did not resemble that of the equatorial regions, but was one in which the temperature was free from extremes: the atmosphere being warm and moist, somewhat resembled that of New Zealand and the surrounding islands, which we endeavour to imitate artificially in our hothouses.

Of the plants which have been preserved to us, the ferns seem to take the lowest rank, and the Coniferæ the highest, the *Calamites*, *Sigillariæ*, and *Lepidodendrons* occupying intermediate positions.† The ferns constituted a most prolific class, occurring in vast quantities in the shales which overlie the coal-seams. The Sigillariæ, Lepidodendrons, and Calamites appear to have formed the greater mass of the coal; and the roots of the former especially (Stigmariæ) penetrate in vast quantities the

* See Sir C. Lyell, "Elementary Geology," 5th edit., p. 399.

† Sir W. Hooker "On the Vegetation of the Carboniferous Period." Mem. Geol. Survey, vol. ii., p. 395.

under-clays or floors of the coal-seams. Coniferous trees, however, formed a considerable portion of the mass of the coal, and seem to have grown in company with the more characteristic plants above mentioned. I now proceed to give a short description of the genera which have been the most prolific and characteristic amongst the flora of this ancient period.

Ferns.—These form a very large proportion of the Carboniferous flora; and, with the exception of their fructification, which has almost always disappeared, are preserved in great perfection. They are represented at the present day by the arborescent forms of the tropics, which flourish in Ceylon, the islands of the Pacific, and the Indian Archipelago, where they are so abundant as to equal in numbers the whole of the phanerogamic plants.

Fig. 1.

Pecopteris lonchitica.
Portion of frond: two-thirds nat. size. From a specimen in the Natural History Museum, Manchester.

The most abundant species in British Coal-measures are—*Pecopteris*, of which there are 60 species;

Sphenopteris, 28 species; *Neuropteris*, 24 species.* Of the 140 species known in Britain, 50 occur in the same formation in North America, some ranging from Nova Scotia as far south as latitude 35°†. It is, however, to be remarked that we know little of the habits of the ferns of the coal-period, whether they grew out of the ground, or attached to the stems of trees; and it is even extremely uncertain what proportion of the large assemblage of species were tree-ferns, as we never find the fronds attached to their stems; and the stems themselves are of extreme rarity.

CALAMITES.‡—This is an abundant genus, and is considered by Brongniart to be represented in our day by the *Equisetaceæ*, of which the horse-tail of our swamps and ponds is a familiar example. This family extends from Lapland to the Equator, attaining the greatest number of species in the temperate zone. The fossil genera differed from the recent, in the absence of the encircling sheaths at the joints. The Calamites almost

Fig. 2

Calamites verticillatus.
From a specimen in the Natural History Museum, Manchester. One-fourth natural size.

* I omit Cyclopteris, as it is still uncertain whether it belongs to the fern tribe.

† Hooker. Ibid., p. 404.

‡ The following is the description of this genus by Lindley and Hutton: "Stems jointed, regularly and closely furrowed, hollow,

always occur leafless, and frequently attain a length of twenty feet.

SIGILLARIA.—This plant is perhaps, *individually*, the most abundant, and has contributed more than any other to the production of coal. It has no living representatives; and about sixty species are known.

Fig. 3.

Fragment of Sigillaria. Half natural size, compressed. From a specimen in the Natural History Museum, Manchester.

Sigillaria may be readily distinguished from the stems of other plants, and of *Lepidodendron*, by the flutes and striæ of the bark being disposed longitudinally, or parallel to the axis of the trunk, and impressed with leaf-scars at regular intervals between the furrows.*

Sigillaria attained a colossal stature. Sir C. Lyell mentions an individual 72 feet in length, found at

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divided internally at the joints by a transverse diaphragm, &c. Leaves (?) verticillate, very narrow, numerous, and simple."—"Fossil Flora."

* The following is the diagnosis of Lindley and Hutton: "*Sigillaria*, stem conical, deeply furrowed, not jointed; scars placed between the furrows, arranged in vertical columns, smooth, much narrower than the interval which separates them."—"Fossil Flora."

Newcastle.* They expand to a breadth of six to eight feet at the base, and from this taper towards the summit. Stems are frequently found standing erect on the roof of the coal, traversing several series of strata.† The character of the foliage is altogether uncertain, but the nature of the root has been clearly demonstrated by Mr. E. Binney, from observations in the Manchester coal-field. Enormous rizomes, or root-stalks, radiating from a central axis, and spreading horizontally, had frequently been observed and described, under the name *Stigmaria ficoides.* They are covered over by multitudes of small circular indentations, from which radiate carbonized rootlets, penetrating the clay in which the rizomes are embedded. They were at first supposed to be a distinct class of plants; but when Mr. Binney discovered, in the neighbourhood of Manchester, several upright stems of Sigillaria attached by their bases to these spreading rizomes, it became evident that these portions stood in the relation of stem and root; and fossil-botany now labours under the disadvantage of having two generic names for different parts of the same plant.‡

The internal portion of this plant (Sigillaria), has rarely been preserved in a state suitable for investigating

* "Elements of Geology." 5th edit., p. 376.

† Several stems were found standing on the upper surface of a coal-seam at Dixonfold near Manchester.

‡ Several fine specimens are in the geological collection of the Museum of Natural History, Manchester. In one of them the upper part of the stem is a large Sigillaria, the lower part passing downwards into massive rizomes (Stigmariæ).

its structure. A silicified fragment, however, fortunately reached the hands of one of the greatest of modern botanists, M. A. Brongniart, who was thus enabled to examine with the microscope the form and arrangement of the tissues. The result of this investigation tended to show that Sigillaria formed a peculiar family of *Coniferæ*, but without any living representative.*

LEPIDODENDRON.†—This is an abundant and large-sized plant of the coal-period; one specimen from the Jarrow coal mine being more than 40 feet in length, and 13 feet in diameter near the base. Notwithstanding its size, it has been shown by Brongniart to have its representative in the diminutive club-moss (Lycopodium) of our mountain heaths. This tribe is generally trailing; but in the tropics there are a few erect species, one of which, *L. densum* of New Zealand, attains a height of three feet.

A fragment of Lepidodendron may be easily distinguished from Sigillaria by the manner in which the leaf-scars are arranged spirally around the stem, giving it a scale-like aspect, from which it derives its name. There are about 40 British species, distinguished by the form and arrangement of these scars.

In the trunks of Lepidodendron, small oval or conical bodies (Lepidostrobi), have frequently been found,

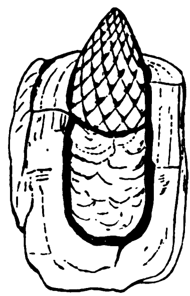
* "Archives du Museum d'Histoire Naturelle," tom. i. 1839.

† Diagnosis:—"Lepidodendron. Stems dichotomous, covered near their extremities by simple linear, or lanceolate leaves, inserted upon rhomboidal areolæ; lower part of the stem leafless; areolæ marked near their upper part by a minute scar." Lindley and Hutton.

often in numbers. They were evidently seed-vessels, and seem to have been divisible into two lobes, the upper conical, the lower cylindrical, and both covered with scales (see fig. 4).

When enclosed within the trunk they are found in an erect position: in other words, with their major axis parallel to that of the tree. Sir W. Hooker, by a series of careful observations, has shown the lepidostrobi to be the fruit of the tree itself, and accounts for their presence in the trunks by supposing them to have been washed in by tropical rains and floods when the trunks themselves were standing hollow and decayed.† The leaves of Lepidodendron were linear, and have been found attached to the stem.‡ The root is supposed, though without any degree of certainty, to be represented by *Halonia*, a portion of a plant covered with projecting scars spirally arranged, and originally supposed to have been a plant allied to Lepidodendron itself. At the same time the root has never been found attached, and it is not improbable that *Stigmaria ficoides* may have constituted,

Fig. 4.



Lepidostrobus ornatus in a nodule of ironstone. In the Bristol Museum. (Hooker.)

* Memoirs of the Geological Survey, vol. ii., part 2, p. 440, with plates.

† In Lord Stamford's museum at Enville there is a specimen of Lepidodendron, collected by Mr. H. Beckett, containing three species of shells—*Unio* (?), *modiola*, and *mytilus*.

‡ For figures of which see the "Fossil Flora."

at least in some of its varieties, the root of both Sigillaria and Lepidodendron.

LYCOPODITES.—This was a genus of plants allied to *Lepidodendron*, with pinnated branches, and leaves inserted all round the stem in two opposite rows, not leaving clean and well-defined scars.

The genus *Knorria* of Sternberg no longer exists as such according to the view of Prof. Göppert, who is of opinion that it is only a form of *Sagenaria* or *Lepidodendron;* and that the most common species in the lower Carboniferous rocks, *Knorria imbricata*, belongs to *Sagenaria Weltheimiana.**

ULODENDRON.—A plant of which the affinities are altogether uncertain. It was of considerable size, reaching 2 feet in diameter; the bark is striated, and is impressed with large circular branch (?) scars at alternate and regular intervals.

CONIFERÆ.—It is not without significance, as bearing upon the theory of "Development," that coniferous trees formed a very important part of the flora of this ancient period of the world's history; so that, as remarked by Sir C. Lyell, their presence precludes us from characterizing the Carboniferous flora as consisting of imperfectly developed plants,—the Coniferæ taking a high position in the ranks of vegetable organization. †

* "Ueber die fossile Flora der Silurischen der Devonischen und unteren Kohlenformation," 1859.

† "Elements," p. 374. The late Mr. Hugh Millar has demonstrated the existence of Coniferæ at a much earlier period—that of the Old Red Sandstone of Scotland. See "Footprints of the Creator," p. 199. Prof. Göppert has recently shown that the Coniferæ make their appearance amongst the upper Devonian rocks.—"Journ. Geol. Soc." vol. xvi.

The prevalent type seems to have been that of the Araucarian or Norfolk Island Pine; but seed-cones resembling those of the genus *Pinus* have also been found. One specimen from the Newcastle coal-field is figured by Lindley.*

The Coniferæ of the coal-period differed from those of the present day in the large size of their pith; and the remarkable, and for a long time inexplicable, fossil, found generally in sandstones, known as *Sternbergia*, has been demonstrated by Professor Williamson to be the pith of these trees.

The little ribbed nodular mass *Trigonocarpum*, found in great numbers throughout the Coal-measures, formerly considered as the fruit of a palm, is now believed to have been that of a coniferous plant, which like the nut of the juniper was enclosed in a fleshy envelope. With regard to the leaves, it is now believed that some which were formerly supposed to belong to palms, as *Næggerathia*, a beautiful fan-shaped frond, were in reality those of Coniferæ, represented in the recent sub-tropical coniferous tree *Salisburia adiantifolia*. Thus it appears that all evidence of the existence of palms amongst the Carboniferous flora has been obliterated.

These details may appear to some uninteresting; but they serve to show how necessary is a large acquaintance with the vegetation of the present, before we can rightly understand that of the past. An acquaintance, however varied, with the recent botanical productions of our own country, would tend to throw little light on the nature of

* "Fossil Flora," vol. iii. p. 43.

that flora which flourished upon the same spot so many ages back. The tropics, and even the diametrically opposite portions of the earth, as New Zealand, Australia, and Norfolk Island, have to be searched, in order to furnish analogous productions; and where these are sought for in vain, as in the case of several Carboniferous genera, we are at a loss how to reproduce before our minds those bygone structures of which we only find the defaced ruins.

Having thus very briefly noticed the plants which were chiefly employed in the production of coal, let us proceed to consider the manner in which this mineral became imbedded, and thus securely stored through countless ages for the use of man.

GÖPPERT'S CLASSIFICATION *of the Flora of the Silurian, Devonian, and Lower Carboniferous Formations.*

Professor Göppert, as the result of an elaborate series of investigations embodied in a work just given to the world, offers the following synoptical classification of the flora of the above-mentioned formations which is specifically distinct from that of the true Coal-measures.

Note.—The student is recommended to study Dr. Hooker's interesting essay "On the Vegetation of the Carboniferous Period as compared with that of the present Day."—Memoirs of the Geological Survey, vol. ii.

I. *Silurian Formation.*

1. Lower Silurian formation . .	17	species.
2. Upper Silurian formation . .	3	„
	20	„

These all belong to the *Algæ.*

II. *Devonian Formation.*

1. Lower Devonian . . . . . 6 species.

Five of these are *Algæ,* one a terrestrial *Sigillaria,*—*S. Hausmanni,* Göpp.—found in Scandinavia.

2. Middle Devonian . . . . . 1 species.

A terrestrial plant *Sagenaria Weltheimiana.*

3. Upper Devonian. . . . . 57 species.

Ferns, Calamineæ, Equisetaceæ, Lepidodendreæ, Lycopodiaceæ, Sigillarieæ, Coniferæ, Næggerathieæ.

1. Lower Carboniferous . . . 108 species.

1. The Carboniferous Limestone contains 47 species, of which one is an *Alga.*

2. The flora of the "Culm," (Upper Limestone Shale ?) contains twenty-three species, of which one plant is marine.

Of all these species of the Lower Carboniferous Rocks only seven pass upwards, and one single plant, *Neuropteris Loshii,* survived into the Permian period.

Fossil Shells of the Coal Period.

The mollusca of the true Coal-measure period are confined to a few genera and species. Bivalves are most numerous, after them Cephalopods, and Gasteropods are rare.

In the upper and middle Coal-measures of England, the most abundant, and often the only shells belong to the genus *Anthracosia*, formerly supposed to be an inhabitant of fresh water, and hence allied to the genus *Unio*. Of this there are a great number of species. The genus *Modiola*, has also its representatives in this part of the series.

Amongst the dark shales of the lower Coal-measures the following genera have their representatives: *Nautilus*; *Orthoceras*—this latter is both scarce and ill-developed; *Goniatites*, very plentiful; *Aviculo-pecten*; *Spirifer* and *Producta*, very rare—one specimen of this last having been found in the Millstone Grit series of Lancashire; *Lingula*; *Posidonia*. Amongst the *Gasteropoda*: *Buccinum*, *Cirrus*, *Pileopsis*, and *Patella*.

For examples of several of the more characteristic forms the reader is referred to the Plate of Fossils.

CHAPTER III.

FORMATION OF COAL.

When Sir William Logan, twenty years ago, was engaged on his great survey of the coal-field of South-Wales, he found it to be an invariable rule that every coal-seam reposed on a bed of clay (underclay) penetrated by the rootlets of *Stigmaria ficoides.** This observation has been extended to every coal-field in Britain, and although the character of the underclay varies considerably, sometimes becoming a hard siliceous stone, yet the presence of the carbonized rootlets shows that it has borne the same relation to the coal as have the softer underclays. This observation of Sir W. Logan established the hypothesis that the plants of which coal is formed grew upon the spot where we now find them mineralized, and that the underclays formed the soil from whence they sprung.

Now these underclays are distinctly stratified, showing that they have been deposited under water; and hence it was supposed that in order to become the receptacles for the growth of luxuriant forests, they must have been elevated into dry land, and then, after having been covered by vegetation, again submerged to be overspread by sands and clays and other sedimentary materials which combine to form the strata of the Coal-measures. This theory required a series of oscillations

* "Geological Transactions," 2nd series, vol. vi.

over a large extent of the earth's surface, which seemed rather improbable, and not in accordance with observations on changes of level which have been made in various parts of the world. That there are slow elevations, and subsidences of the surface in operation more or less extensively, is proved by phenomena exhibited on our sea-coasts,* where in some cases old sea-beaches are found at elevations far beyond the reach of the waves, and in others, where forests, and even towns, are known to be engulfed; and the whole of the geological record teaches us that similar vertical movements have been taking place from the earliest periods.

Along the eastern coasts of South America, Mr. Darwin has described the existence of a succession of terraces, rising in tiers from the sea-level up to an elevation of 1200 feet. He has shown that each of these terraces has in turn been for a long period subjected to the action of the waves, which have swept away a vast quantity of material, and hollowed out caverns in the rock.†

Now as the whole of the land, from the highest terrace down to the level of the ocean, has evidently been under the sea, to have attained its present position it must have been elevated, and each coast line marks a pause in the process of elevation. Here is an example of a constant change of level, with pauses; and it probably furnishes an illustration of Nature's mode of action during the coal-period. The process, however, in this case must be *reversed*, and instead of periodical elevations

* For many examples see Lyell's "Principles of Geology."

† "Voyage of the Beagle," vol. iii. p. 200.

it is necessary to infer a slow and gradual subsidence of the sea-bed, accompanied by pauses marked in many cases by the formation of a seam of coal.

But another question requires to be cleared up. The coal-seams are associated with strata deposited under water; and all recent investigation strengthens the probability that this water was not fresh, but marine. In the northern coal-fields of England, some of the coal-seams are covered by black shales containing remains of fishes and marine shells, as *Goniatites*, *Aviculopecten*, *Orthoceras*; and along the coast of Dunbar, in Scotland, bands of limestone, with marine shells, as *Spirifer*, *Producta*, &c., rest upon coal-beds, and on the upright stems of Sigillaria.* In coal-measures belonging to the higher portion of the Carboniferous series, bivalves which were formerly supposed to belong to the fresh-water genus *Unio*, have since been found in the same stratum with the marine genera *Modiola* and *Spirifer*,† and have been ranged by Professor King with the marine, or brackish-water genus, *Anthracosia*. Mr. Binney has shown the probability, that the little coiled shell (*Microconchus carbonarius*), is in reality a coiled *Serpula* or *Spirorbis*, which attached itself to the coal-plants;‡ and lastly, the minute crustacean abundant in shales, and supposed to have belonged to the fresh-water

* These limestones, as I am informed by Mr. Salter, contain fossil representatives of the Carboniferous Limestone of England; and it is well known that a portion of the Coal-measures of Scotland are of earlier date than those of England.

† As I am informed by Mr. Binney.

‡ It is scarcely necessary to remark that Serpula is a marine annelide.

genus *Cypris*, is with more probability referred to the marine genus *Cythere*. Without asserting, therefore, that there are no fresh-water strata associated with the Coal-measures, I think we may conclude that the whole formation has been emphatically of marine origin—a conclusion at which we might arrive on other grounds, when we consider that the formation was at one period continuous over the greater part of Central America, and would have required for its generation a lake of a size at least six times the area of all the great lakes of America united.

There are two conclusions which strike us most forcibly when reflecting on the formation of our coal-fields;—the enormous subsidence of the sea bed, and the lapse of time it must have required to produce a series of strata, with their coal-seams, in all several thousand feet in thickness.

Recollecting that every bed of true coal represents a land-surface, when we find, as in the case of the coal-field of South Wales or of Nova Scotia, strata with coal-beds through a thickness of 10,000 or 14,000 feet, it is evident that this is a measure of the actual sinking of the sea-bed for this one geological period; or, to take an example:—the height of Mont Blanc is about 15,000 feet; now the vertical displacement which the South Wales coal-field underwent, was nearly sufficient to have brought the summit of the Alps to the sea level.

Of the lapse of time in the formation of our coal-fields we cannot have the faintest conception; it is only measured by Him with whom a thousand years are as

one day. But the magnitude of the time is not surpassed by the boundlessness of the providential care which laid up these terrestrial treasures in store for His children, whom He was afterwards to call into being. Let me therefore dismiss this profitless subject with one illustration. Mr. Maclaren, by a happy train of reasoning, for which I must refer the reader to his "Geology of Fife," arrives at the conclusion that it would require a thousand years to form a bed of coal one yard thick. Now, in the South Wales coal-field there is a thickness of coal of more than 30 yards, which would have required a period of 30,000 years for its formation. If we, now, assume that the 15,000 feet of sedimentary materials was deposited at the average rate of two feet in a century, corresponding to the rate of subsidence, it would have required 3,807,000 years to produce this coal-field.*

I have spoken of the difficulty of conceiving frequent *elevations* of the sea-bed during the long period of subsidence in order that a land surface might be laid dry for the growth of vegetation. A much more probable supposition is, that the coal-plants were fitted to grow either partially submerged or at the sea-level. Analogy would lead us to this conclusion in the case of *Sigillaria*, *Calamites*, &c., and amongst these abundant tribes dense forests of reeds and grasses probably grew.

The great swamps at the estuary of the Mississippi,

* In this estimate I have adopted a medium between two extreme estimates given by Lyell, "Elements," p. 386, 387. For a good resumé of this subject see Mr. Jukes' "Manual of Geology," p. 95 et seq.

along the coasts of Louisiana, Nova Scotia, and the tropical lagoons of the African coast, furnish us with the nearest representations of the nature of those forests that have produced our coal-beds; but none of them are strictly analogous. The physical conditions of the coal-period stand alone, and we cannot but conclude that they were ordained beforehand for a great and evident purpose.

Fig. 5.

Succession of Strata in Lower Coal-measures, near Wigan, Lancashire.

The strata which are associated with the coal consist of sandstones, which were once sand; shales and fire-clays which were once fine mud. Some of the shales are so highly carbonaceous as to be nearly black, and form impure coal called "bass." Bands of limestone occur in the higher beds of the Coal-measures in England, and

throughout the greater extent of the formation in Scotland.

The sandstones are frequently rippled, and obliquely laminated, showing the prevalence of currents; they also contain fragments of drifted plants. The shales have generally been deposited slowly and tranquilly. The general succession of strata which accompany coal is shown in the annexed section, taken from the neighbourhood of Wigan, and belonging to the lower Coal-measures, or Gannister series.

Of Britain it may be emphatically said, "whose stones are iron," for clay-ironstone abounds in the shales of every coal-field, either in the form of nodules or in thin courses. She has also erected more altars to Vulcan than any other country, and the products of her Carboniferous rocks—the coal, ironstone, and limestone—have enabled her to take the foremost place in industrial arts.

Besides iron-ore, the clays contain fronds of ferns and fragments of other plants in fine preservation, together with remains of fishes and shells.

The coal-formation is very frequently traversed by vertical fractures or *faults*, which, within a few yards or feet, completely change the series of strata and the mineral character of the district. These faults are actually vertical dislocations of the rocks, the beds having been upheaved or depressed, as the case may be, tens, hundreds, or even thousands of feet. Many examples will be produced when we come to treat of the coal-fields; but I may mention that some of the faults which traverse the coal districts of Lancashire and Staffordshire

dislocate the strata to the amount of 600, 700, or even 1000 yards! How graphically has that grand old geologist, the patriarch of Uz, described these throes of our great mother earth: "He putteth forth his hand upon the rock, he overturneth the mountains by the roots!"

The Coal-measures of England rest upon a series of hard and coarse sandstones and shales—called Millstone Grit; this again on a thick series of black shale, the Yoredale rocks, which pass downwards by the intermixture of thin courses of limestone into the great calcareous deposit, the Carboniferous Limestone. This last formation attains in Derbyshire a thickness of 5000 feet, and is surcharged with marine fossils throughout; indeed it is almost wholly composed of the shells of mollusca, the calcareous habitations of corals, or the broken skeletons of Crinoidea or "stone-lilies." These last must have covered the bottom of the ocean in countless myriads, forming miniature forests, which rose generation after generation upon the accumulating layers of their perished ancestors, until their remains were sufficient to form thick beds of limestone, extending for many miles in every direction. In some parts of Derbyshire and Yorkshire the limestone appears to be composed of little else than the disjointed stems of encrinites.

The Coal-measures are overlaid by the Permian formation, consisting of three members: the lower composed of red and purple sandstones, marls, calcareous conglomerate, and breccia; the middle of magnesian limestone of the north-eastern counties; the upper of gypsum, marls, and sandstones. This formation is unconform-

able to the Coal-measures, and to the Trias which succeeds it.

Next in succession is the Trias or New Red Sandstone, which, in the absence of the Permian strata, sometimes rests directly upon the Carboniferous rocks. It consists of two members, the Bunter and Keuper; the middle member, the Muschelkalk, being absent in Britain.

The Bunter Sandstone consists of three members: the lowest, soft red and variegated sands; the middle, quartzose conglomerates and red pebbly sandstone; the upper, soft streaked and variegated sands. Upon this the Keuper series rests unconformably, the upper surface of the Bunter Sandstone being frequently eroded and waterworn. The Lower Keuper Sandstone is introduced by breccia, and passes upwards into the Red Marl.

We are now in a position to comprehend the formation of a bed of coal in olden time.

Let us suppose that a certain bed of coal has been completed by the growth of luxuriant plants over a low-lying tract subject to inundations from the sea. Rising ground of granitic or schistose rocks in the distance defines the margin of the basin and the boundaries of a continent from which the sedimentary materials of the coal-strata are derived. That growth of vegetation marks a period of rest; but now a slow subsidence of the whole tract commences. The brackish waters of the estuary, and the salt waters from the ocean invade the jungle, carrying dark mud in suspension, with floating stems of trees and fronds of ferns. Presently the

mud subsides and covers in one uniform sheet the accumulated vegetation of centuries. The process of subsidence goes on, while the sea-currents and rivers pour into the estuary fine sand and mud, in which branches and stems of trees from the uplands are included. This process continues until the sinking of the ocean-bed either altogether ceases or is counterbalanced by the rapidity with which the sediment is deposited. The basin becomes gradually shallower, and the plants begin to reappear, commencing perhaps at the coast, and creeping seaward until the whole basin is again overspread by a forest of huge cryptogamic trees, arborescent ferns, and conifers, with a dense undergrowth of giant grasses. These, generation after generation, flourish and die, their leaves, branches, and trunks falling around and gradually accumulating till the pulpy mass attains a thickness of 20, 50, or 100 feet. The process concluded, the basin again commences to subside, the waters return and bury the mass for thousands of centuries; stratum after stratum accumulates, till the vegetable pulp is subjected to the pressure of, it may be, thousands of feet of solid matter. Meanwhile chemical as well as mechanical changes ensue, and in process of time what was once a forest is changed into a bed of coal. By a repetition of this process, with local variations, we may conceive the formation of any number of coal-seams, amounting, in some districts, to 50 or 60, and embraced within a vertical thickness of several thousand feet of shales, clays, and sandstones. Ages roll on, the strata are moved from their foundations; upheaved from the sea-

bottom, the breakers and currents sweep away a portion of the covering, and the mineral treasures are brought within the reach of mining industry.

Tabular View of the Trias, Permian, and Carboniferous Series in England.

New Red Sandstone or Trias	Keuper . .	Red marl
		Lower Keuper sandstone
	Bunter . .	Upper mottled sandstone
		Conglomerate beds
		Lower mottled sandstone
Permian Rocks		Upper Permian marls
		Magnesian limestone
		Lower Permian or rothe-todte-liegende
Carboniferous Rocks	Upper Carboniferous	Upper Coal-measures with limestone (Ardwick)
		Middle Coal-measures
		Lower Coal-measures or Gannister series
	Lower Carboniferous	Millstone grit
		Upper limestone shale
		Carboniferous limestone
		Lower limestone shale

Old Red Sandstone and Devonian rocks.

Having given a brief sketch of the nature of coal, its origin, and the strata with which it is associated, we are now prepared to pass on to the consideration of the coal-fields.

PART II.

CHAPTER I.

THE GREAT COAL-FIELD OF SOUTH WALES.

THE coal-field of South Wales is the largest in England; and, with the exception of that of Nova Scotia, contains a greater vertical thickness of strata than any coal-field in the world, amounting to upwards of 10,000 feet.

It is separated by Caermarthen Bay into two unequal portions. That to the east of the bay stretches to Pontypool, in Monmouthshire, a distance of 56 miles, and is the larger portion. The smaller extends to St. Bride's Bay, a distance of 17 miles, and is washed by the waves of the Atlantic. The greatest transverse diameter is 16 miles, in the meridian of Neath, in Glamorganshire.

The general form of the coal-field is that of an oval basin or trough, lying nearly east and west. It is deeply indented by the bays of Swansea and Caermarthen, which overspread the upturned edges of the strata as they cross from shore to shore. It will therefore be understood, that from the oval form of the coal-field, the highest strata occur near the central axis; and that in

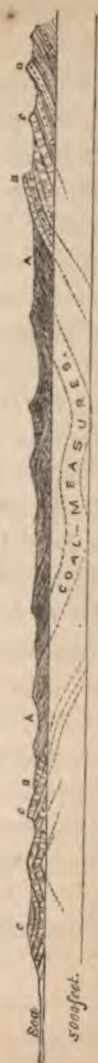
proceeding from this line either to the north or south, we cross transversely the up-tilted edges of the beds, reaching in succession lower coal-seams with their accompanying sandstones and shales, then the Millstone Grit, Carboniferous Limestone, and finally, the Old Red Sandstone. Owing, however, to the occurrence of an arch, or anticlinal bend of the strata near the centre of the trough, the above description is only approximately correct, as in reality the highest strata occur a little to the north and south of the central axis.*

Scenery.—Along its northern borders, the coal-field partakes of a mountainous character, rising into lofty tabulated hills indented by deep valleys, along whose sides the beds of coal crop out, and are worked by means of galleries far into the hills.

Beyond the limits of the coal-measures, the siliceous sandstones

* These phenomena are illustrated by the transverse section (Fig. 6), where the Coal-measures are shown to be bent upwards in the centre of the trough.

NORTH.



SOUTH.

Fig. 6.—SECTION ACROSS THE COAL-FIELD OF SOUTH WALES.
Length about 20 miles.

A. Coal-measures, with coal. B. Millstone Grit. C. Carboniferous Limestone. D. Old Red Sandstone.

and conglomerates of the Millstone Grit form an encircling zone; and from beneath these, the still harder rocks of the Carboniferous Limestone rise to the surface, and present towards the north a range of scarped terraces, often broken through by valleys and gorges which have been determined by faults, but on the whole preserving a general direction parallel to the *strike** of the beds, and attaining elevations of 2000 feet. Along the southern boundaries of the coal-field, these lower Carboniferous formations produce rich and varied scenery, but not of so bold and elevated a character as along the northern margin.

Surveys.—Following the track of the Ordnance Surveyors, the geological delineation of this great coal-field had been commenced by Sir E. Logan, and subsequently completed by Sir H. T. De la Beche and Mr. Williams, during 1837 and following years. They have left us a series of beautifully executed maps and sections, presenting the details as far as they were discoverable at a time when the coal-field had been very partially explored by mining operations. Of these documents, it was stated by one competent to judge, that they at once placed the landed proprietors in the possession of information which it would have taken 30 years to acquire by the advance of mining enterprise.

* The "strike" is a term to express the horizontal direction of the strata, and is perpendicular to the "dip."

General Succession of Strata, and their thicknesses, in Monmouthshire.

Coal-measures.—Shales, with ironstones; sandstones, including the "Gower series," and *coal-beds,* of which there are about 25 more than 2 feet thick. Total thickness, 11,650 feet.

Millstone Grit (Farewell Rock.)—Beds of hard sandstone and conglomerate, with partings of shale (Merthyr Tydvil), thickness 330 feet.

Carboniferous Limestone.—Upper beds consisting of alternating dark shales with bands of limestone, passing downwards into massive beds of the latter, thickness 1000 feet.

Old Red Sandstone.—Conglomerate, red and brown sandstone, marls, and calcareous cornstones, 8000 to 10,000 feet in thickness.

Details.—Westward of Swansea Bay the Millstone Grit disappears, and the lower Coal-measures rest directly upon the Carboniferous Limestone. At Haverfordwest this latter also vanishes, and inland from St. Bride's Bay the Coal-measures repose on Lower Silurian Rocks.

Anthracite and Bituminous Coals.—It is well known that a remarkable change comes over the nature of the coal-beds when traced from the east towards the west. While in the former direction they are bituminous, or gaseous, upon reaching the centre of the area, the same coal-seams lose their bituminous qualities, and gradually pass into anthracite. Sir H. De la Beche states that this change takes place along a plane, dipping gently towards the S.S.E.; so that in the same spot, while the coals at the base of a hill may be anthracitic, those

which outcrop along the heights above may be bituminous. Nor is this alteration in the character of the coals accompanied by outbursts of igneous rock, or by violent crumplings and contortions of the beds, as is the case in the Alleghany mountains of America, where a similar change has been produced; on the contrary the strata are but slightly thrown out of the horizontal position. Other causes must therefore be sought for. I believe that the doctrine of central heat is a sufficient explanation. When we recollect that the temperature increases in proportion to the depth, and that in South Wales the lower coal-beds have been originally overlaid by several thousand feet of strata, since swept away, the heat to which they have thus been subjected was probably sufficient to have driven off, wherever escape was possible, the gaseous elements. There are, however, many difficulties which appear inexplicable, especially the fact of the coal of the western districts having become more anthracitic than that of the eastern.*

Coal-seams.—There are beds of coal throughout the whole series of strata of 10,000 feet in thickness, but they occur in greatest number towards the centre and lower parts of the formation. They are also subject to variations in extent, thickness, and quality; for in coal, as in everything else, Nature abhors uniformity. By a comparison of various sections, the average number of coal-seams of greater thickness than two feet, has been found to be 25, giving a total thickness of 84 feet of workable coal.

* For an explanation of the change in the coals of South Wales, I must refer to the views of Sir H. De la Beche, Memoirs of the Geological Survey, vol. i.

The following summary of the known coal-seams in several important districts, has been kindly supplied by Mr. Salter, of the Geological Survey: I have not thought it necessary to insert all the names of the coals:—

Name of District.	Total No. of Coals.	No. of Coals above 2 feet in thickness.	Principal Coals.
1. Merthyr Tydvil	54	16	Mynydd Isslwyn, 5/6; Upper Troed, 4/0; Yard, 3/2; Upper 4 feet. Troes y fran, 8/6; Lower coal, 4/0.
2. Ebbw Vale	52	8	Elled vein, 3/4; Big vein, 4/9; 3-quarter vein, 3/4; Engine vein, 5/9; Gloien Goch, 4/0; Old coal, 5/6.
3. Cwm Telery . . .	29	13	Soap vein, 2/8; Elled and Big veins, Bydyllog, 5/0; Old Coal, 5/0.
4. Pont-y-Pool	25	12	Mynydd Isslwyn, 5/6; Red vein, 8/6; Rock vein, 8/0; Meadow vein, 9/6; Bottom, 5/0.
5. Penllergare and Pont-y-gwasted	51	26	Goch vein, 13/6; Big vein, 6/0; Tryglo, 5/0; Gwendrath, 3/0; Coed Bach, 2/6; Pimp quart, 3/9.
6. Llandibic, Caermarthenshire	—	19	9-Foot, Pimp quart, 3/9; Gwyryd, 3/0; Stanllyd, 6/9.
7. Llangeinor, Glamorganshire	31	14	Llangeinor, 4/0; Coedafydd, 5/0; Upper 6-foot, Furnace vein, 12/0.
8. Cambrian Iron-Works	..	6	
9. Bryn Coch Dyffryn	13	8	
10. Llw chwr and Ren-Clawdd, Glamorganshire	68	16	Faith seam, 4/0; Great vein, 9/0; Glo Broight, 4/6; Rock vein, 5/0; Fiery vein, 4/0; Frog-lane, 3/0; Big vein, 6/0.
11. Penllergare to Bishopstown, near Swansea	62	25	Church vein, 4/0.
12. Cwm Trwch, near Ystradgynlas, Brecknock	9	6	Nine-feet vein, Brass vein, 4/0; Try Glo, 2/0; Lumpy vein, 2/0.

Ironstones.—The lower measures are the chief repositories of ironstone, as at Merthyr Tydvil, and at Taffe Vale near Cardiff. They are seldom more than four inches in thickness. The following is an analysis of the principal bands, made at the Museum of Practical Geology.

Analysis of Ironstones.

	Carb Iron.	Earthy Matter.	Metal.
Upper vein, Ystradgunlas ..	86·0	14·0	41·5
Another vein, Do. ..	72·4	27·6	34·9
Cwm Phil vein	75·4	24·6	36·4
Pendaren red vein ..	75·4	24·6	36·4
,, Jack vein ..	55·5	44·5	26·6
Black-band, Pontypool ..	79·5	20·5	38·4

The yield of these Coal-measure ores, even in conjunction with the hæmatite from the Carboniferous limestone, is not sufficient to supply the enormous consumption, and large quantities are imported from Northamptonshire and other districts. In 1858 there were, in the anthracite district, 15 furnaces in blast, and in the bituminous district, 132 furnaces, producing in all 886,478 tons of iron.*

Faults.—Considering the vast extent of this coal-field, the fractures of the strata are not considerable. Those which have been traced are found generally to range in a direction perpendicular to the strike of the beds. A system of faults has been traced on the maps of the Geological Survey traversing the northern edge of the basin, which, after crossing the escarpments of the Millstone Grit and Carboniferous Limestone, are

* "Mineral Statistics," for 1858, by Mr. R. Hunt.

lost amongst the extensive tract of Old Red Sandstone of Brecknockshire.

Resources.

In attempting to estimate the duration of the supply of coal from this vast repository I am aware of the difficulty of the task. When we regard the enormous amount of fuel which is stored up throughout a thickness of strata out of which might be cut a mountain about three times the height of Snowdon, having a basis of a thousand square miles, and which, as Mr. Vivian has shown, could supply the whole consumption of Britain for nearly 5000 years, it seems almost profane to assert that at least one half of this store must lie for ever beyond our reach, and thus, as far as man is concerned, to have been made for nought. If, therefore, there are those who consider 4000 feet as too narrow a limit, it will be satisfactory to them to be assured that they have here a store of fuel well-nigh limitless, and which if it had been drawn upon to its present extent since the days of the Noachian deluge, would even still be unexhausted.

I shall however here adopt, for the reasons stated in a former chapter, the limit of 4000 feet, which will require a deduction of one-half the full quantity. From this we must deduct one-third for the quantity already raised and for waste, and also disregard all seams of coal under two feet in thickness.

Note.—I must refer the reader to the closing pages of this Essay for an exposition of my reasons for adopting a depth of 4000 feet as the vertical limit of coal-mining. Part iv., page 164.

Estimate of the Mineral Resources of the South Wales Coal-Basin.

1. Superficial area, ...	906 square miles.
2. Greatest thickness of Coal-measures with coal	10,000 feet.
3. Number of coal-seams from 2 feet and upwards, 25, giving a thickness of	84 feet of workable coal.
4. Total quantity of coal (corrected for denudation)	48,000 millions of tons.
5. Deduct one-half for quantity below 4000 feet, leaving	24,000 millions of tons.
6. Deduct one-third for waste and quantity already extracted, leaving for future supply	16,000 millions of tons.

7. Dividing this quantity by 8 millions of tons,* the average annual produce, we find that the supply will last, *at the present rate of consumption*, 2000 years.†

This coal-field, if opened up to an extent proportional to that of Yorkshire, ought to yield 13 millions of tons per annum.

Fossil Remains.

Mr. Bevan has recorded the following fossils from the lower Coal-measures. They are generally found immediately over each of the coal-seams along with which they are mentioned. Many of the species, it will be observed, are identical with those occurring in the Car-

* The quantity raised in 1857, was 8,919,100 tons; but in the following year it declined.

† Mr. Vivian's estimate is 5000 years, which would be nearly that of my own, if we add the quantity of coal below 5000 feet.

boniferous Limestone, yet they are stated by Mr. Bevan to lie in strata above the Millstone Grit.*

1.	Three-quarter coal,	Terebratula hastata.
2.	Bydellog coal ..	Athyris, Producta scabricula.
3.	Daren Pins coal	Myalina, Anthracosia (unio).
4.	Old coal ..	Anthracosia, Modiola, traces of crustacea.
5.	Red vein ..	Cardiomorpha.
6.	Blue vein ..	Anthracosia, Modiolopsis, Spirorbis.
7.	Bottom vein ..	Spirifer bisulcatus, and fish.
8.	Thin coals in the Millstone Grit with marine shells.	

From this list we miss the Goniatites, Aviculo-pectens, Lingulæ, &c., which are so characteristic of the lower Coal-measures in the north of England.

CHAPTER II.

BRISTOL AND SOMERSETSHIRE COAL-FIELDS.

At an unusually short distance from the base of that range of Oolitic escarpments which stretches in an ever-varying line from Gloucestershire to Dorsetshire, lies the Bristol coal-field. The thick series of formations which in the midland counties intervene between the Coal-measures and the Lias, are here either greatly reduced in depth or altogether absent; and hence we

* Transactions of the British Association, 1858.

Fig. 7.—SECTION ACROSS THE BRISTOL COAL-FIELD.

WEST. Cotteswold Hills. EAST.

A. Old Red Sandstone.
B. Carboniferous Limestone.
C. Millstone Grit.
D. Coal-Measures, with coal.
5. Lower Oolite.
4, 3, 2. Upper, Middle, and Lower Lias.
1. New Red Marl (Trias).

may pass from the one formation to the other within a distance of a hundred yards.*

The northern part of the coal-field forms a trough lying north and south, narrowing towards its northern limits, and expanding in the opposite direction, till, east of Bristol, it reaches a width of seven miles. The beds rise at high angles along the edge of the basin and beyond the edge of the Coal-measures. The Millstone Grit and Carboniferous Limestone form parallel belts. Upon the upturned edges of these more ancient formations the New Red Marl and Lias rest almost horizontally (see Section No. 7). South of Bristol, the boundary of the coal-field, marked by the range of limestone hills, sweeps round to the westward, and is lost under the sea beyond Nailsea Moor, near Clevedon in Somersetshire. South of this the Coal-measures underlie the Liassic formations of Dundry Hill, and encircle the large mass of Carboniferous Limestone near Congresbury.

* This district is illustrated by the Geological Survey Maps, 19, 35, and Sections, sheets 14, 15.

Over the greater part of this area the coal-formation is buried at moderate depths under newer horizontal strata.

Along the southern boundary of the coal-field the Carboniferous Limestone of the Mendip Hills reaches the surface, trending from west to east, till lost beneath the Lias and Oolite near Frome. This easterly trend or "strike" of the Carboniferous strata, where we have means of observation for the last time, is highly interesting and important. It leads to the inference that the coal-formation underlies a band of country stretching in the direction of the Thames valley, over which (though composed of Oolitic formations) coal may at some future day be reached at moderate depths. Mr. Godwin-Austen, by a high process of geological reasoning, has shown the probability that this coal-bearing band extends right across the whole of the south of England to the north of France.*

The extreme length of this coal-field, from its northern apex at Cromhall to the northern flanks of the Mendip Hills, is about 25 miles, the strike of the beds north of the valley of the Avon being north and south, and over the area south of this line from west to east. About one half of the northern portion is overlaid by horizontal strata of the Triassic and Oolitic periods, and of the southern part 9-10ths are covered over in this manner; yet the existence of the underlying coal-field is abundantly proved, not only from theoretical considerations but by actual sinkings for coal. Shafts penetrating the Lias and Red Marl into

* Journ. Geol. Soc. London, vol. xi.

the coal have been sunk at Paulton and Timsbury, and another near Radstock, commencing in the upper beds of the Lias, reaches coal at 200 fathoms.*

The succession of strata in the neighbourhood of Bristol has been determined by Mr. D. Williams,† and is as follows:—

Succession of Strata near Bristol.

Lias ..	.. Lower, Middle, and Upper Lias.	
Trias ..	.. Red Marl.	
	Dolomitic conglomerate.	
Coal-Measures	Upper Series, with 10 coal-seams ..	1,800 feet
	Central, or Pennant grit, 5 coal-seams ..	1,725 „
	Lower shales, 36 coal seams	1,600 „
Millstone Grit ..	Hard silicious grits, &c.	950 „
Carboniferous Limestone	.. ..	2,338 „

There is thus a total thickness of strata with coal of 5,125 feet, separated into two divisions by a series of hard, massive sandstones (Pennant grit), which will prove a serious obstacle to sinking in search of the lower coals. Of the 51 coal-seams above mentioned only 20 are 2 feet and upwards in thickness, producing 71 feet of coal.

In estimating the resources of this coal-field, large deductions must be made on several accounts. First, for the disturbed, folded, and contorted state of the strata along the borders of the Mendip Hills and other places; secondly, because along the northern borders the strata plunge so rapidly towards the centre of the

* "Lectures on Geology," by Mr. R. Etheridge, 1859. A little book containing much valuable information about the Bristol coal-field; and to its author I am indebted for many details concerning this district.

† Mem. Geol. Survey, vol. i., p. 207.

basin that many of the coal-seams are there buried at depths between 4000 and 5000 feet, with the Pennant grit superimposed; and thirdly, so much of the coal-field is concealed by newer formations that we cannot as yet speak confidently regarding the strata in some places. I have therefore deducted one-third in the following estimates.

Estimate of Resources.

1. Area (of which only 45 square miles are not concealed by newer formations)	150 square miles.
2. Greatest thickness of measures with coal ..	5,125 feet.
3. Number of coal-seams from 2 feet and upwards, 20, giving a thickness of coal of ..	71 feet.
4. Total original quantity of coal (corrected for denudation)	4,148 millions of tons.
5. Deduct for quantity inaccessible, spoiled, &c., one-third, leaving	2,766 " "
6. Deduct for quantity already worked out, one-tenth, leaving	2,489* " "
7. Deduct for quantity below the depth of 4,000 feet, one-fifth; leaving for future supply about	2,000 " "

8. Dividing this quantity by the average produce, 620,000 tons, we find that this coal-field would require 3225 years to become exhausted.

The chief conclusion to be drawn from the above results is, that this coal-field is capable of yielding at least five times the present quantity of coal if worked to the extent of its capabilities.†

* *i. e.*, under the newer formation, 1742 millions. The actual coal-field contains only 747 millions.

† The production above stated (620,000 tons) is calculated by subtracting 500,000 due to the Forest of Dean, from 1,120,000, the total quantity raised in both coal-fields in 1858. Hunt's "Mineral Statistics," 1858.

CHAPTER III.

FOREST OF DEAN COAL-FIELD, GLOUCESTERSHIRE.

THE structure and resources of this coal-field are now thoroughly understood. It forms a more perfect "basin" than any other coal-field in England, as the strata everywhere dip from the margin towards the centre, except at one part of the western side, where the oval outline is interrupted for a short distance.*

The Coal-measures are surrounded by belts of Millstone Grit and Carboniferous Limestone, which generally rise considerably above the tract of the Coal-measures they enclose, just as the banks of a lake are higher than the lake itself; and the Carboniferous Limestone in turn rests upon a bed of Old Red Sandstone. The general structure resembles that of the South Wales coal-field in miniature, and the transverse section (Fig. 6) illustrates the coal-basin of the Forest of Dean as well as that to which it more especially refers.

Scenery.—The scenery around the skirts of this coal-basin is rich and varied. The eastern ridge of the Carboniferous Limestone overlooks the vale of the Severn, and commands the escarpment of the Cotteswold Hills of Gloucester and Somerset. At the opposite side of

* See Maps of the Geological Survey, 43, S.E. and S.W., and Mr. Sopwith's large map in the Museum of Practical Geology.

Note.—The Royal Forest covers a space of 23,000 acres, of which 11,000 are in timber. Deer formerly abounded, but are now almost extinct.

the coal-field the eye rests upon the Vans of Brecon 2,700 feet in height, and the ranges which mark the northern bounds of the great South Wales coal-field. The limestone ridge on which you stand is cut into lofty cliffs lining the gorge of the Wye, and in its extension southwards towards Chepstow, produces those remarkably terraced cliffs which render the scenery of that part of the river as beautiful as it is peculiar.

The area of the coal-field is about 34 square miles. It contains 31 seams of coal, of which only 8 are of a thickness of 2 feet and upwards; and the total series, as stated by Sir H. De la Beche, is as follows:*—

1. Coal-measures with 31 coal-seams ..	2,765	feet
2. Millstone Grit	455	"
3. Carboniferous Limestone	480	"
4. Lower Limestone Shale	165	"
5. Old Red Sandstone	8,000	" or more.

In the Carboniferous group there is a decrease by two-thirds in the thickness of the strata as compared with the Bristol district. Over the centre of the basin the strata lie nearly horizontally. On approaching the eastern borders they rise very rapidly, but along the opposite, or western edge, the lower beds spread out considerably, and in consequence have a much larger horizontal range than those higher up in the series. The coals are being gradually worked from the margin of the basin where they crop out, towards the centre where they are deep; on which account it is probable that progressive mining operations will be much hindered by the accumulation of water in the old workings.

* Mem. Geol. Survey, vol. i. p. 203.

The Forest of Dean in 1858 contained 10 iron furnaces, of which 4 were in blast, producing upwards of 23,000 tons of pig-iron. The ore used is derived from the clay-ironstone of the Coal-measures, from hæmatite extracted from the Carboniferous Limestone, and from other extraneous sources.

The Horse.—In one of the coal-seams, called "Coleford High Delf," there occurs one of those interruptions in the regular course of the strata, which tend to throw much light on the original conditions under which coal was formed, but are an occasion of serious loss and disappointment to the proprietor. River channels filled with sand or clay, traversing coal-seams, occur in almost every coal-field, and are known as "rock-faults," and "horse-backs;" but the case to which I have alluded is so remarkable, and has been so fully investigated, that it will serve as a general illustration of these phenomena in other districts.* The description is by Sir H. De la Beche,† who says—The horse with its branches resembles a channel cut amongst a mass of vegetable matters in a soft condition. It ranges S. 31° E. for a length of two miles, and a breadth of 170 to 340 yards. A number of minor channels communicating with each other and the main channel are named "Lows." Mr. Buddle compares the *horse* to the bed of a river, and the *lows* to smaller streams cutting only a lesser depth. The

* Mr. Jukes has very fully described these *horses* or *rock-faults* in the "Thick Coal" near Dudley, in his "Memoir on the South Staffordshire Coal-field," p. 45.

† Mem. Geol. Survey, vol. i, p. 156.

channels are filled principally with sandstone, which extends over the coal-seam and forms its roof.

Resources.

1. Area of coal-field	34 square miles.
2. Greatest thickness of Coal-measures ..	2,760 feet.
3. Number of coal-seams from 2 feet and upwards 8, giving a total thickness of ..	24 "
4. Total original quantity of coal (corrected for denudation)	842 millions of tons.
5. Deduct for loss and quantity worked out one-third, leaving for future use	561 millions of tons.

6. This, at the present rate of production of 500,000 tons,* would last for 1120 years.

This result shows, that like the two previously described coal-fields, that of the Forest of Dean is capable of yielding a very much larger supply than is the case at present.†

CHAPTER IV.

COAL-FIELD OF THE FOREST OF WYRE, WORCESTERSHIRE.

A COAL-FIELD of about as large a superficial extent as that of the Forest of Dean stretches from the northern end of the Abberley Hills, and spreading out under the Forest of Wyre, ultimately becomes contracted northwards to a narrow band lining the banks of the Severn south of Bridgenorth.

* With this estimate I have been furnished by Mr. L. Brough, H. M. Inspector of Mines.

† My colleague, Mr. Bristow of the Geological Survey, estimates the resources of this coal-field somewhat higher, as he informs me that several coals under two feet in thickness can there be worked at a profit.

The Coal-measures repose on a bed of Old Red Sandstone, consisting of red marls, sandstones, and cornstones (concretionary earthy limestones), and are overlaid by a thick mass of Lower Permian strata, composed of red sandstones and marls with calcareous conglomerates, and marly breccia,* very fully developed, at Enville. This Permian breccia has excited much interest regarding its origin; for Professor Ramsay has shown that it bears a strong resemblance to accumulations originating in glaciers, and spread over the sea-bottom by floating ice, such as that of the Boulder clay of the Glacial epoch. If this theory be correct, a vast change must have come over the climate of these countries between the coal-period and that which immediately succeeds it.

This coal-field has not been fully explored; but as far as is known, the coal-seams which it contains are both thin and of inferior quality. The following series occurs near the western margin, as exhibited in Mr. Aveline's section drawn across this district.†

Section of Coal Strata, Forest of Wyre.

	Feet.	Inches.
1. Sandstone and shale	76	0
2. Coal	1	10
3. Sandstone and shale	24	0
4. Coal	2	0
5. Sandstone and shale	39	0
6. Coal	4	0
7. Sandstone, shale, &c.		

* "Breccia" is a word used to designate strata formed of angular pebbles, "conglomerate" being confined to strata where the pebbles are rounded or waterworn.

† Sections of the Geol. Survey, sheet 50; also Geol. Map, 55, N.E.

It is probable that these seams extend under the greater part of the Coal-measure tract, and their outcrops have been traced for several miles from north to south.

The Coal-fields of the Clee Hills, Salop.

Two small outlying coal-tracts, remnants of a formation which once spread continuously from South Wales and Gloucestershire, are perched on the summits of the Titterstone and Brown Clee Hills in Shropshire, at a height in the latter case of 1780 feet above the sea, and if lighted up with the combustible materials with which they are stored, would serve as beacon-fires for many a mile around.

These coal-fields are rather more than a mile each in diameter, and are capped by a bed of hard basalt, to which, owing to its power of resistance to marine denudation, the hills probably owe their preservation. On these flat-topped hills are planted several small collieries, whose shafts pierce the basalt before entering the coal. The vent from which this igneous rock has been erupted is situated in the Titterstone Clee Hill; and from this orifice the basalt has apparently been poured forth in the form of liquid submarine lava, at some period after the Coal-measures were formed.* The thickness of the coal formation is but small containing only two or three thin coal-seams, and the strata rest generally directly on Old Red Sandstone; but representatives both of the Carboniferous Limestone and Millstone Grit are interposed at the eastern side of the Titterstone Hill.

* See horizontal section of the Geological Survey, sheet 36.

I have referred to these districts more on account of their geological interest, than for any economical value they may be supposed to possess.

CHAPTER V.

SHREWSBURY COAL-FIELD.

THIS coal-field forms a narrow band extending from the base of Haughmond Hill, east of Shrewsbury, to the banks of the Severn near Alberbury, a distance of about 18 miles. Like the coal-field of the Forest of Wyre, the coal-strata repose on the older rocks without the intervention of the Millstone Grit and Carboniferous Limestone; but in this instance the fundamental rocks belong to the Cambrian and Lower Silurian periods. Notwithstanding its length it is seldom more than a mile in breadth; and in its lower part contains two or three coal-seams which have been worked to a small extent, but are not of sufficient value to induce mining operations far from the outcrop.*

The Coal-measures are overlaid by Lower Permian strata, consisting of red and purple marls and sandstones, surmounted at Alberbury and Cardeston by a remarkable stratified breccia, composed of angular fragments of white quartz, and Carboniferous Limestone cemented by calcareo-ferruginous paste. The "Alberbury breccia" may be regarded as the remnant of an

* Sir R. I. Murchison, "Silurian System," p. 63.

old shingle-beach formed round a coast-line, composed of Carboniferous and Silurian rocks.

In the upper part of this coal-field a band of limestone* occurs with estuarine and marine organisms, some of which were at first supposed to be of fresh-water origin. It contains a small crustacean *Cythere*, a bivalve shell, *Anthracosia*, and an annelide, *Spirorbis carbonarius*. Now it is a remarkable instance of the persistency of some calcareous strata over large areas, that this band of limestone, seldom more than a foot in thickness, can be traced in the Coal-measures of Coalbrook Dale and the Forest of Wyre southward, of Lancashire northward, and of Warwickshire eastward, representing an area of about ten thousand square miles; and throughout this expanse it is always found associated with those uppermost coal-strata, which preceded the introduction of the Permian rocks.

The coal-fields of the Forest of Wyre, the Clee Hills, and Shrewsbury, together with a fourth district extending from the base of Caer Caradoc to within a few miles south of Shrewsbury, are of so valueless a nature in regard to their coal deposits, that I do not consider it necessary to produce an estimate of their resources. They have all been formed in the vicinity of old land-surfaces, and around lines of coast composed of more ancient rocks. The strata themselves belong generally to the higher part of the coal-series, which throughout England is but sparsely enriched with beds of coal.

* This limestone is described by Sir R. I. Murchison (" Siluria," p. 321.)

CHAPTER VI.

COAL-FIELD OF COALBROOK DALE, SHROPSHIRE.

This coal-field has a triangular form, with its base in the valley of the Severn, near Coalbrook Dale; and its northern apex at Newport. Along its western side it is bounded partly by a great fault, which brings in the New Red Sandstone, and partly by the Silurian rocks of the Wrekin, which rises with its smooth and arched back to a height of 1320 feet above the sea, and half that amount above the general level of the country around. Along its eastern side the coal-field is bounded by Permian strata, under which the Carboniferous beds appear to pass, but diminished both in thickness and in productiveness of coal.

The general dip of the strata is eastward; and in making a traverse to the foot of the Wrekin, we cross in succession the base of the Coal-measures, the Millstone Grit, Carboniferous Limestone, a bed of basalt, and at length reach the Silurian rocks which form the general foundation to the Carboniferous formations in this district. This succession of strata is illustrated by the section. (Fig. 8.)

This coal-field has been mapped and described by the Geological Surveyors,* and is the subject of an elaborate memoir by Mr. Prestwich, published in the Geological

* Geological Maps, 61 N.E., and Sections Sheet 54, 58.

actions.* The strata are
kable for the variations they
go within narrow limits—
beds rapidly disappearing,
hanging their characters.
; the eastern borders the
r strata consist of calcareous
as and gravels, resembling
nic ashes, mixed with reddish
ed clays. The coal-seams
so more than usually subject
nange; and towards the
n border, where they pass
the Permian strata, several
e upper coal-beds die out
a gently sloping plane;
are even entertained that
me catastrophe will be found
olve the whole of the coals,
followed under the newer
tion. It is satisfactory how-
o learn, that in the new col-
belonging to Lord Gran-
which passes through about
rds of Permian strata, the
eams have been found at
proper depth and thickness,
as the sinking has yet been
d—316 yards. If the coals

* 2nd Series, vol. v.

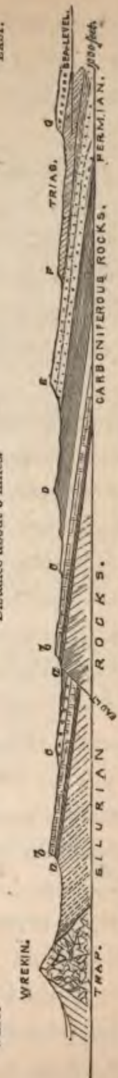


Fig. 8.—SECTION ACROSS THE COAL-FIELD OF COALBROOK DALE.
Distance about 5 miles.

D. Coal-measures, with coal. E. Permian Rocks.
c. Millstone Grit. F, G. New Red Sandstone. { G. Conglomerate. F. Lower Mottled Sandstone.
b. Carboniferous Limestone.
a. Basalt.

should be found persistent under the Permian rocks, there is a large area beyond the borders of the coal-field itself, where they may be reached at depths under 2000 feet.

The strata of this coal-field are much broken by faults. The largest of these is the western boundary fault; another, the *Lightmoor fault*, traversing the centre of the coal-field from north to south, has a "throw" of about 100 yards: west of this fault the coal-beds are almost exhausted. There are also many transverse fractures.

Organic Remains.—These are extremely varied, and have been enumerated in detail by Mr. Prestwich. They occur principally in the ironstones, of which the principal depositories are the Penneystone and Crowshaw bands. Fish: *Hybodus, Gyracanthus formosus, Cochliodus, Megalichthys Hibberti, Holoptychius,Pleuracanthus.* Crustacea: *Limulus,* a genus allied to the king-crab; *Glyphea, Cypris inflata.* Mollusca: *Nautilus, Orthoceras, Bellerophon, Conularia, Spirifer bisulcatus, Leptæna scabricula, Pecten, Anthracosia* (Unio), *Nucula, Lingula, Terebratula.* Insects: one or more species of scorpion; two beetles of the family *Curculionidæ,* and a neuropterous insect, resembling the genus *Corydalis,* and another related to the *Phasmidæ.**

There are several courses of ironstone measures, which in 1857 yielded 109,722 tons of pig-iron, from 27 blast-furnaces;† the Coalbrook Dale and Lilleshall companies being the largest producers.

* Lyell, "Elem. Geol.," p. 388. † "Mineral Statistics," 1857.

The coal over a very large portion of this field has been nearly exhausted, as will be apparent to any one who crosses it by the Wolverhampton and Shrewsbury railway, where, over a large area, nothing but dismantled engine-houses and enormous piles of refuse from abandoned coal and iron mines meet the eye. The collieries have gradually migrated from the western outcrop towards the east. Under these circumstances, it is probably within the mark to deduct from the original mass of coal two-thirds for the quantity already worked out. Nearly 20 years back, when Mr. Prestwich was engaged in his survey, the district west of the Lightmoor fault was almost destitute of coal.

Resources.

1. Area of the coal-field	28 square miles.
2. Greatest thickness of Coal-measures ..	1,200 feet.
3. Number of coal-seams of upwards of 2 feet, in thickness, 6, giving a total thickness of	27 feet of coal.
4. Original quantity of coal (corrected for denudation.)	43 millions of tons.
5. Total quantity worked out and lost, about 28 millions, leaving for future use ..	15 ,, ,,

Which at the present rate of consumption would be exhausted in about 20 years.

Note.—This estimate only applies to the actual coal-field. As already stated, the Coal-measures dip under Permian and New Red Sandstone along the eastern margin, and already have these rocks been invaded by at least one coal-shaft, which will speedily be followed by others, should the coal-beds prove continuous—but of this there are at present some doubts.

CHAPTER VII.

THE COAL-FIELDS OF NORTH WALES.

General Structure.

An interrupted tract of Coal-measures extends from the northern slopes of the valley of the Severn, south of Oswestry, to the mouth of the estuary of the river Dee, in Flintshire, crossing the river at the entrance to the Vale of Llangollen. The Coal-measures are overlaid by Permian strata on the south, and New Red Sandstone on the north, and repose on beds of Millstone Grit and Carboniferous Limestone, each about 1000 feet in thickness. These form a range of lofty hills with terraced escarpments looking westward, and exhibit a very noble and striking feature when viewed from behind Llangollen, where they assume the form of a long line of ramparts, the strata being piled like lines of masonry, tier above tier. This rampart forms the physical line of demarcation between Wales and England, though the conventional boundary extends into the plain along the eastern slopes.

These calcareous hills are frequently traversed by faults, and are full of lodes rich in argentiferous galena; the most remarkable of which is the "Great Mineral vein," coinciding with a line of fault traversing the Denbighshire coal-field from south-east to north-west, and which in 1857 yielded 2496 tons of ore.

The coal-fields here described form part of the counties of Denbigh and Flint: and north of the valley of the Alyn become separated into two portions, by the upheaval along the line of a great fault of the lower Carboniferous rocks.* The tract south of this fault is called the Denbighshire coal-field; that to the north, the Flintshire coal-field—each of which will now be described separately.

DENBIGHSHIRE COAL-FIELD.

This coal-field commences about three miles south of Oswestry, where the New Red Sandstone begins to rest directly on the Millstone Grit, and extends northward by Oswestry, Ruabon, and Wrexham, to the north of the valley of the Alyn, which winds through a deep defile, and exposes in its banks an almost complete section of the coal formation. The length of the coal-field is about eighteen miles; and it is

* This is one of the largest faults in England, and has been traced from the sea on the coast of Merionethshire, through Bala Lake into Cheshire. See maps of Geological Survey, sheet 74, N.E. and S.W.

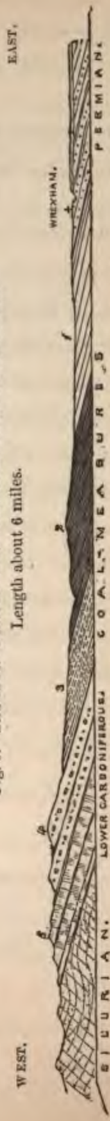


Fig. 9.—SECTION ACROSS THE DENBIGHSHIRE COAL-FIELD.
Length about 6 miles.

1. Upper Coal-measures without coal. 2. Middle Coal-measures with coal. 3. Lower Coal measures with thin coals.
4. Millstone Grit. 5. Carboniferous Limestone.

about four miles in breadth at Wrexham, where crossed by the section. (Fig. 9).

The general succession of the strata is as follows:—

			Thickness.
1. Trias, or New Red Sandstone.			
2. Lower Permian rocks			1,000 to 2,000 ft.
3. Coal-measures	1. Upper series,	1,000 feet	2,800 to 3,000 „
	2. Middle (with coals).	800 „	
	3. Lower (thin coals)	1,000 „	
4. Millstone Grit			800 to 1,000 „
5. Carboniferous Limestone			1,000 to 1,500 „

The lower Permian strata consist of red and purple marls and sandstones, and may be seen along the banks of the Dee west of Overton, and in the brook which flows eastward of Wrexham.

The Coal-measures may be classed under three divisions. The upper consists of red and grey sandstones and reddish clays, and contains only a few very thin and worthless coals: of these beds there are good sections along the banks of the Alyn, west of Gresford. The middle series constitutes the coal-bearing strata, and contains the following coal-seams of good quality, besides several others not worth mentioning: this series corresponds, with slight variation, to that in Flintshire.

Succession of Coal-Seams, Denbighshire Coal-Field.

Upper and Lower sulphureous coals—not worked.

1. Smith Coal	2 ft.	2in.	to	2 ft.	4 in.
2. Drowsall Coal (good quality) ..	3	0			
3. Powell Coal	3	3			
4. Two-yard (with "Ribbon" coal under)	5	0	to	6	0
5. Crank Coal(brassy ironstone measures occur here) ..	2	8	to	3	0
6. Brassy Coal (Black-band ironstone occurs here)	5	0			
7. Main Coal	6	0	to	7	6
Total thickness of coal	27	1	to	30	1

The lower measures contain several coal-seams, varying from 2 to 3 feet, which have been but little sought after in the presence of the thick seams from the middle series.

There are several valuable beds of ironstone, the principal being "the brassy" and "black-band," from which in one year 12,560 tons were raised for the Brymbo furnaces.

The remains of fish are abundant in this coal-field, and have been classed by Sir P. Egerton under the following genera: *Rhizodus*, *Cœlacanthus*, *Platysomus*, and *Palæoniscus*. The black-band ironstone is very full of fish-scales, teeth, &c., and also contains a bivalve shell of the genus *Anthracosia*. In the lower Coal-measures the black shales contain *Goniatites* and *Aviculo-pecten*, as is the case in Lancashire and Yorkshire.*

Though containing coal-seams of good quality, and reaching thicknesses of 7 feet, there is a large tract lying between Brymbo and Ruabon over which the coal lies perfectly undisturbed; nor have the coals been followed to any great depth, one of the deepest collieries being only 173 yards.† I think, therefore, I am justified in placing the quantity already worked out at only 1-10th of the whole.‡

* For this information I am indebted to Mr. E. Binney.

† Westminster Colliery.

‡ I am confirmed in this estimate by Mr. Beckett, of Wolverhampton, who is well acquainted with this and the adjoining coal-fields.

Resources.

1. Area of the coal-field	47 square miles.
2. Greatest thickness of Coal-measures	3,000 feet.
3. Number of coal-seams above two feet, 7, giving a thickness of	30 „ of coal,
4. Original quantity (corrected for denudation)	727 millions of tons
5. Deduct for quantity worked out 1-10th, and for loss 1-4th, leaving for future use	490 „ „

6. Which at the present rate of production (527,000 tons) would last for 930 years.

This result shows what is the fact, that the quantity of coal raised in this coal-field is far below that which it is capable of producing. Collieries are, however, now being erected along the Chester railway, and in a few years the production will probably be doubled. The great depth of the "Drift" accumulations (sand, gravel, and clays) has operated to keep this coal-field partially concealed.

The quantity above estimated is included within a maximum depth of 2000 feet; a depth of 4000 feet would embrace a band of country containing above one-half more.

CHAPTER VIII.

FLINTSHIRE COAL-FIELD.

THIS coal-field is disconnected with that of Denbighshire by the upthrow of Carboniferous Limestone and Millstone Grit over a small tract between Gresford and Hope. From this it extends along the western side of the estuary of the Dee to Point of Air, a distance of 15 miles; but

throughout a considerable part of its range the productive portion is very narrow, and greatly broken by faults.

The general dip of the beds is towards the north-east, and there is no doubt but that they underlie the New Red Sandstone of the Cheshire plain; for they actually reappear on the Cheshire coast at Parkgate, where they are upheaved along a line of fault.*

The following is the general section of this coal-field:

	Ft.	In.
1. "*Four-foot Coal* { Coal, Cannel } ..	4	0
Strata	41	0
2. "*Bind*" *Coal*	2	6
Strata with ironstone	62	0
3. { *Hollin Coal* (in three beds)	6	6
Cannel	1	6
Strata with ironstone	29	0
4. *Brassy Coal*	3	0
Strata	82	0
5. *Main Coal*	7	0
Strata	180	0
6. *Lower Four-foot Coal* (supposed) ..	4	0

It will be observed that the *Main* and *Brassy* coals of Flintshire and Denbighshire correspond; that the "Hollin" coal of the former is the "Two-yard" coal of the latter, while the "Powell" coal represents the "Bind" coal. The intermediate ironstone-measures also correspond. The "Lower four-foot" coal in the Flintshire section cannot yet be said to have been satisfactorily determined. The general quality of the coal is excellent.

* Map of the Geol. Survey, 79, N.E. Also Section Sheet 43, with description. For much information regarding this coal-field I am indebted to Mr. Beckett, of Wolverhampton.

In the Lower Coal-measures, below all the strata above named, Mr. Binney informs me that there are several thin seams with roofs of black shale, containing *Goniatites* and *Aviculo-pecten*, corresponding to the Gannister coals of Lancashire and Yorkshire. These coals are visible in a brook section south of Hope, which in another part displays very beautifully the unconformable superposition of the New Red Sandstone on the lower Coal-measures.

The strata of the Flintshire coal-field rarely attain a great depth. If we cross the centre of the district from west to east, we find the beds repeatedly upheaved along dislocations ranging north and south. The result is, that the greater portion of the coal being placed so near the surface has already been exhausted, and probably not more than one-half remains for future use. The valley of the Dee seems to offer favourable positions for deep shafts; and already the coal is being won under high-water mark on Mostyn Bank.

There can scarcely remain a reasonable doubt of the continuation of the coal-formation from Flintshire to Lancashire under the intervening tract of New Red Sandstone.

Resources.

1. Area of the coal-field	35 square miles.
2. Number of coal-seams at least 5, giving a thickness of	25 feet of coal.
3. Original quantity (corrected for denudation) ..	54 millions of tons.
4. Quantity raised, one-half; ditto spoiled, and lost 1-10th; leaving for future use	21 " "

5. At the present rate of production of 515,000 tons, the coal-field would be exhausted in about 40 or 50 years.

CHAPTER IX.

ANGLESEA COAL-FIELD.

Crossing a mountainous region of 45 miles in breadth from the Flintshire coal-field to the centre of Anglesea, we find a series of Carboniferous strata on the whole similar to those just described.

The Anglesea coal-field forms a band of country stretching from Hirdre-faig to Malldraeth Bay, a distance of nine miles. Its breadth at Malldraeth Marsh is a mile and a half. The Coal-measures are overlaid unconformably by red sandstone, conglomerate, and marl, of Permian age, and from beneath the coal-strata the Millstone Grit and Carboniferous Limestone rise in succession, their base resting on highly-contorted and metamorphic schists of Cambrian or Lower Silurian age. The existence of this coal-tract is entirely due to an enormous fault, having at one point a down-throw on the north-west of 2300 feet. Through its agency the Carboniferous strata

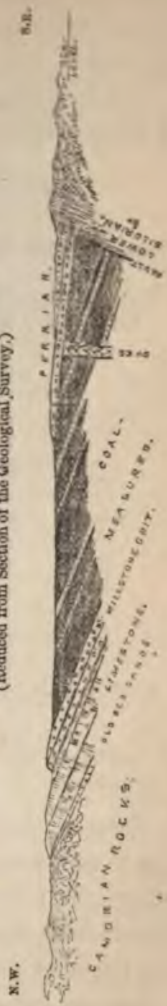


Fig. 10.—SECTION ACROSS THE ANGLESEA COAL-FIELD.
(Reduced from Section of the Geological Survey.)

have been dropped down, and are protected on all sides by the ancient Silurian rocks. (See Section 10, page 85.)

The following is the general succession of the strata as determined by Professor Ramsay.*

Succession of Strata, Anglesea Coal-Field.

		Ft.	In.
Permian Rocks—	Red sandstone, marl and conglomerate ..	195	0
Coal-measures— 1309 feet.	*Coal* ("Glopux") lying in lumps	9	0
	Shale	51	0
	Coal	3	0
	Shale	63	0
	Coal	4	0
	Strata	75	0
	Coal (irregular)	2	0
	Strata	43	0
	Coal	6	0
	Strata	90	0
	Coal (with cannel roof) ..	1	8
	Strata (about)	300	0
	Coal (supposed Berw Uchaf coal, in 3 beds with partings)	7	6
	Strata	650	0
	Coal (perhaps in Millstone Grit)	2 to 3	0
Millstone Grit—	Yellow sandstone and conglomerate ..	200	0
Carboniferous Limestone	Gray and black limestone, and sandstone, with *Producta*, *Spirifer*, Corals, &c.	450	0

Some of these coal-seams crop up against the base of the Permian strata, proving the great discordance between the formations. A greenstone dyke rises in a line of fault near Berw colliery, but appears not to enter the Permian strata.

* See description of Horizontal Section of the Geological Survey, sheet 40; also Geol. Map, sheet 78.

Another small coal-tract lines the banks of the Menai Straits near Carnarvon.

The Anglesea coal-field contained (1857) five collieries, producing about 4500 tons of coal.

CHAPTER X.

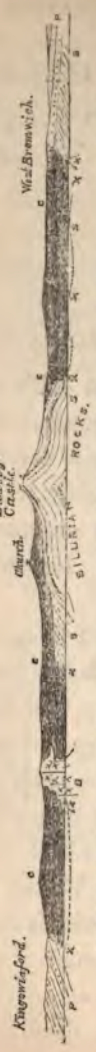
SOUTH STAFFORDSHIRE COAL-FIELD.

THIS coal-field extends from the Clent Hills on the south to Brereton, near Rugeley, on the north, a distance of 21 miles, and is of an average breadth of seven miles. It appears to have been upheaved bodily along two great lines of fracture, which range in approximately parallel directions from north to south. Beyond these lines, Permian and Triassic rocks set in.

Aspect of the Coal-field.—This district is one of extreme productiveness in coal and iron; and its proximity to the towns of Wolverhampton, Dudley, and Birmingham, has imparted an extraordinary impetus to these foci of industry. But indeed it may be said, that the whole line of country connecting these towns, a distance of 12 miles, forms one great workshop: and on a fine night, the spectacle from the walls of Dudley Castle, which rises from the centre of the coal-field, is one which has scarcely a parallel. The whole country within a radius of five or six miles is overspread by collieries, iron-foundries, blast-furnaces, and the dwellings of a

Fig. 11.—SECTION ACROSS THE SOUTH STAFFORDSHIRE COAL-FIELD.
Distance about 6 miles.

WEST. EAST.



P. Permian Rocks. C. Coal-measures. S. Upper Silurian Rocks. B. Basalt. X Faults.

dense population; and from amidst the thick smoky atmosphere, the tongues of fire from the furnaces shoot up an intermittent light which illuminates the whole heavens. But the spectacle before our eyes does not represent the whole sum of human labour; for whilst ten thousand hands are at work above ground, one-half as many perhaps are beneath the surface, hewing out the coal which is to be the prime-mover of the whole machinery.

Physical Geology.—It has been shown by Mr. Jukes,* that while the Lower Carboniferous rocks were being deposited over other parts of England, a band of country stretching from Shropshire across South Staffordshire and Warwickshire was dry land; consequently there is no Carboniferous Limestone or Millstone Grit, and the Coal-measures repose directly on an eroded surface of upper Silurian rocks, which at Sedgley,

Note.—The Section at the side of the page is reduced from one by Mr. Jukes.

* "South Staffordshire Coal-field," Mem. Geol. Survey, 2nd edition, (Preface.) See Geol. Maps, 62 S.W., 62 N.W., and corresponding Sections.

Dudley, and Walsall, rise from beneath the Coal-formation. (See Section, Fig. 11).

The general succession of the strata, as given by Mr. Jukes, is as follows:—

		Ft.
Trias—Bunter Sandstone 1,200	1. Upper mottled sandstone ..	500
	2. Conglomerate beds ..	500
	3. Lower mottled sandstone ..	200
		1,200
Permian [Lower Permian] 1,000 to 3,000	1. Breccia of felstone, porphyry, & Silurian rocks 2. Red marls, sandstone, & calcareous conglomerate	1,000 to 3,000

Coal-measures—Southern district.

		Ft.
Upper Coal-Measures—1,300	Red and mottled clays, red and grey sandstone and gravel beds	800
Middle Coal-Measures—510 ..	1. *Brooch Coal*	4
	Strata, with ironstone	130
	2. *Thick Coal*	30
	Strata with "Gubbin ironstone" ..	20
	3. *Heathen Coal*	4
	Strata with ironstone	109
	4. *New Mine Coal*	8
	Strata with ironstone	16
	5. *Fire-Clay Coal*	7
	Strata	30
	6. *Bottom Coal*	12
	Strata with several courses of ironstone	140

Upper Silurian Rocks—1. Ludlow rocks, with Aymestry limestone.
2. Wenlock and Dudley Limestone and Shales.
3. Woolhope Limestone (?)
4. Llandovery Sandstone.

Coal-seams.—From the above list it will be seen, that in the Dudley district there are six workable seams of coal, giving a total thickness of 65 feet. The most remarkable of these is the "Ten-yard," or "Thick coal,"

of a general thickness of 30 feet—a source of enormous wealth to the district. It underlies a large area, at a moderate depth; and has either been worked out, drowned, or destroyed to such an extent, that probably little more than one-tenth remains to be won. It is rather subject to "rock-faults," or "horse-backs," instances of which are given by Mr. Jukes;* and the author has seen an instance at Baremoor colliery, where the whole mass of coal has been replaced by sandstone—the junction being formed of a series of interlacings.

Thinning of the Strata southwards.—In the northern part of the coal-field, at Essington and Pelsall, this massive bed becomes split up into nine distinct seams, with a combined thickness of exactly 30 feet of coal; but separated by 420 feet of sandstones and shales, all of which are absent to the south of the "Great Bentley fault." This remarkable thinning out of the strata takes place in a distance of five miles from north to south, and is an additional instance of the vastly higher amount of persistency in the coal-seams than in the sedimentary strata with which they are associated.

Dip of the Beds.—North of the Great Bentley fault, the general dip is from east to west; and there is an extensive tract of about ten miles in length extending to Beaudesert, and three in breadth, over which the lower coal-seams lie undisturbed, as those which are worked at Essington and Wyrley occupy a higher position. At Brereton there are several shafts sunk through Conglomerate beds of the New Red Sandstone, under which formation the coal is extensively worked.

* "South Staffordshire Coal-field," &c., p. 45 et seq.

TRAP ROCKS.

Basalt.—In several localities over the southern portion of the coal-field, several varieties of igneous rocks are found, frequently burrowing through and altering the Coal-measures, and sometimes resting upon them. The finest exhibition is the basaltic mass of Rowley Regis, or "Rowley rag," forming a hill about two miles in length, and 820 feet in height. This basalt assumes the columnar structure, affording examples of prisms as perfect as those from the Giant's Causeway in Ireland. Mr. Jukes considers that this rock has been poured out, in the form of a lava-flow, during the coal-period; for the beds of coal dip under the basalt, and have been followed till found "blackened," or charred, and utterly worthless.*

At Pouk Hill, near Walsall, is another mass of columnar basalt, in which there are vertical, horizontal, bent, and radiating columns.

Greenstone.—In the Lower Coal-measures, a sheet of greenstone spreads almost without interruption from the base of Rowley Regis, through the centre of the district, to Wolverhampton, Bilston, and Bentley. This would appear to have been a lava-flow of earlier date than the basalt, but ejected from the same vent, which we may suppose to be situated near the centre of the hill. There are also beds of volcanic ashes and gravel associated with the Upper Coal-measures at Hales Owen, probably

* "South Staffordshire Coal-field," &c., p. 120.

nearly contemporary in their formation with the Rowley basalt.

Ironstones.—The ironstones occur in beds, associated with shale, and are the principal repositories of the fossils. The principal bands are:—

1. The Pins and Pennyearth ironstone-measures.
2. The Grains ironstone } below the Thick Coal.
3. The Gubbin ironstone } below the Thick Coal.
4. The New Mine ironstone.
5. The Pennystone do., with marine fossils, *Producta, Avicula-pecten, Lingula*, &c., an *Echinus*, and fish-teeth and bones.
6. Poor Robin, and White ironstone—only local.
7. Gubbin and Balls ironstone.
8. Blue Flats, Silver Threads, and Diamond ironstone.

Fossils.—Fish: *Gyracanthus formosus* (ichthiodorulites), *Holoptychius, Megalichthys Hibberti, Cochliodus, Pœcilodus.* Molluscs: *Producta, Conularia, Lingula, Myalina, Anthracosia bipennis* (in coal), *Aviculo-pecten scalaris ;* Annelides; and the usual Coal-measure plants.*

Resources.

In order to arrive at an estimate of the resources of this coal-field, it is necessary to consider the northern and southern halves separately; as the former contains about three-fourths of the original quantity of coal, the latter only one-tenth.

1. Area of coal-field	93 square miles.
2. Average thickness of workable coal above 2 feet	16 yards.

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* These fossils have been determined by Mr. Salter, of the Museum of Practical Geology.

3. Total original quantity of coal (corrected for denudation)	3,072	millions	of tons.
4. Of this, the Northern part contained ..	1,024	"	"
Deduct 1-4th, leaving for future use ..	768	"	"
5. The Southern part (south of the Bentley fault) contained	2,048	"	"
Deduct 9-10ths, leaving about	205	"	"
6. Total quantity remaining	973	"	"

Which at the present rate of consumption would be exhausted in about 200 years.

There are, in the South Staffordshire coal-field, 425 collieries; at which 4,995,780 tons of coal, and 959,000 tons of ironstone, were raised in 1858. The average production of iron from this ore being 33 per cent.

The number of blast-furnaces in the district is 147; in which 597,809 tons of pig-iron were smelted in 1858, and 777,171 tons in 1856.*

CHAPTER XI.

NORTH STAFFORDSHIRE COAL-FIELD.

THE North Staffordshire coal-field, though of smaller area than that of South Staffordshire, has vastly greater capabilities. The strata are about four times as thick, with twice the thickness of workable coal, and instead of being bounded on each side by enormous faults, which at one step places the coals at almost unapproachable depths, the Coal-measures of North Staffordshire dip under the Permian and Triassic rocks along a

* "Mineral Statistics," 1858.

Fig. 12.—GENERAL SECTION ACROSS THE NORTH STAFFORDSHIRE COAL-FIELD.

SOUTH-WEST. NORTH-EAST.

1. New Red Conglomerate.
2. Permian Rocks.
3. Upper Coal-measures.
4. Middle Ditto, with coal.
5. Lower Coal-measures, with thin coals.
6. Millstone Grit.

line of many miles at the south-western border of the coal-field, and under these formations coal may be obtained at a future day. Moreover, there are none of those protrusions of igneous rocks which have produced so much injury to the coal-beds near Wolverhampton, Dudley, and Hales Owen. This coal-field has the shape of a triangle, with its apex to the north at the base of Congleton Edge, the eastern side is formed of Millstone Grit, and the westerly of New Red Sandstone or Permian strata. Along the south the Coal-measures are overlaid by Permian marls and sandstones, and these strata run far up into the heart of the coal-field by Newcastle, along the line of a great fault, which ranges north-north-west towards Talk-on-the-Hill.*

On that division of the coal-field extending eastward of this tongue of Permian rocks are situated the Potteries, a group of populous towns, from which all parts of the world are supplied with china-ware rivalling that of Dresden, with vases and various kinds of vessels modelled after Etruscan patterns, but adorned

* Geological Survey Map, 72, N.W.

with paintings from natural models, executed with a perfection of colouring and outline to which the Etruscans never attained; here also are produced those tesselated pavements which adorn so many of our churches and public buildings. For the production of these works of art chalk-flints are brought from the south of England, decomposing granite from Cornwall, gypsum from Chellaston, siliceous chert from Derbyshire. The coarser kinds of earthenware and tiles are made in large quantities from the clays of the Upper Coal-measures, and the coal supplies the heat for the baking ovens.

*Succession of Strata, North Staffordshire Coal-field.**

		Greatest thickness. Feet.
Permian Rocks	—Red and purple sandstone, marl, and cornstones (with plants), strata slightly unconformable to the coal-measures	600
Coal-Measures— 5,000 feet.	1. *Upper*—Brown sandstones, greenish conglomerate (like the volcanic ashes of S. Staffordshire) with thick beds of red and purple mottled clays; thin coals ..	1,000
	2. *Middle*—Sandstone, shales, with ironstone, and about 40 coal-seams	4,000
	3. *Lower*—Black shales and flags, with Wetley Moor thin coals. (*Goniatites, Pecten.*)	1,000
Millstone Grit	—Coarse grits, shales, and flags ..	4,000
Yoredale Rocks,	—Black shales, &c., with marine fossils	2,300
Carboniferous Limestone	.. ..	4,000 to 5,000

If we compare the above section with that of South

* See Horizontal Sections of the Geological Survey, Sheets 42 and 55, with explanations. This coal-field was surveyed by Mr. W. W. Smyth, and the author, in 1856-7.

Staffordshire we cannot but be struck with the vast accession of sedimentary materials in this northerly direction.

Succession of Coal-Seams.

	Ft.	In.		Ft.	In.
1. *Peacock Coal* ..	6	6	12. *Coal*	3	0
Strata	20	0	Strata	270	0
2. *Spencroft*	3	9	13. *Birches' Coal* ..	4	6
Strata	121	0	Strata	300	0
3. *Great Row* ..	8	0	14. *Ten-feet Coal* ..	6	0
Strata	71	0	Strata	102	0
4. *Cannel Row* ..	5	0	15. *Bowling Alley* ..	4	6
Strata	54	0	Strata	81	0
5. *Wood Mine* ..	2	0	16. *Holly Lane* ..	5	10
Strata	29	0	Strata .. .	84	0
6. *Deep Mine* .	2	8	17. *Sparrow Butts Coal*	4	9
Strata	361	0	Strata	222	0
7. *Winghay Coal* ..	4	6	18. *Flats*	3	0
Strata ..	377	0	Strata	108	0
8. *Ash* or *Rowhurst* ..	8	0	19. *Frog's Row* ..	4	6
Strata	121	0	Strata	30	0
9. *Burnwood* ..	5	0	20. *Cockhead*	4	6
Strata	68	0	Strata	420	0
10. *Golden Twist* ..	3	6	21. *Bullhurst*	4	0
Strata	486	0	Strata	60	0
11. *Mossfield*	4	7	22. *Winpenny* ..	3	0
Strata	30	0			

Lower Coal-measures, with two thin coals of Wetley Moor. Besides the above there are 15 other seams of no value.

Ironstone measures.—This coal-field contains several very valuable bands of ironstone, of which the following are the principal: 1. *Top red mine* of Silverdale, 18 inches thick; 2. *Gubbin ironstone*, which is filled with the bivalve shell *Anthracosia*; 3. *Pennystone*; 4. *Two-feet mine*; 5. *Burnwood ironstone*.

Fossil Remains.—Fish: Messrs. Garner and Molyneux have been collecting with much success specimens of the ichthyolites, which occur in profusion in some of the ironstone bands and their associated shales, the "Bassy mine" being the most prolific. They occur principally in the higher strata of the coal-field, and the following genera are recorded:* *Dipterus* (?),† *Palæoniscus ornatissimus*, *Gyrolepis*, *Cœlacanthus*, *Rhizodus*, *Holoptychius*, *Ctenodus*, *Megalichthys*, *Saurichthys* (?)† *Ctenacanthus*, *Hybodus*, *Diplodus*, *Ctenoptychius*, *Petalodus*, *Helodus*, *Pleuracanthus*, *Onchus* (?) *Orthocanthus* (ichthyodorulites, sometimes 12 inches in length), *Septacanthus*, *Gyracanthus*. Of Mollusca, the only examples found in the middle and upper measures have been nine or ten species of the genus *Anthracosia*, and in the lower measures *Aviculo-pecten* and *Spirorbis* (*Microconchus*) *carbonarius*. Plants of most of the usual Carboniferous genera are abundant.

Faults.—The faults of this coal-field are not numerous except in the neighbourhood of Talk-on-the-Hill. There are, however, several very large dislocations: one of which forms the boundary of the coal-field along its north-western edge. It runs along the western base of Congleton Edge and west of Talk, throwing down the New Red Marl of the Cheshire basin on the north-west

* Trans. Brit. Association, 1859, p. 103. These genera (I understand) have been verified by one of our highest authorities, Sir Philip De M. Egerton.

† I have placed a (?) after *Dipterus* and *Saurichthys*, as the former of these genera is generally considered exclusively Devonian, the latter Triassic.

against the Carboniferous rocks on the south-east. This dislocation is more than 500 yards, and its direction is north-north-east. Another fault, with a downthrow on the east of 350 yards, passes by Newcastle and east of Hanchurch; and at Hanford there is a third and parallel line, with a downthrow of 600 feet, on the same side. East of Longton the coal-field is bounded by a large fault, which was visible near the entrance to the railway tunnel when it was being made: it throws in the New Red Sandstone on the east side.

Resources.

This coal-field has been worked only to a small extent in comparison with its enormous resources. As the coal-bearing strata are upwards of 5000 feet in thickness, it is evident that in some parts of the district, towards the borders of the Permian rocks, the lower coals can never be reached, so that we must make large deductions (about one-third) for the quantity which is not available.

1. Area of coal-field	75 square miles.
2. Total thickness of measures.. ..	5,000 feet.
3. Number of workable coal-seams, 22, with a thickness of	94 feet of coal.
4. Total original quantity of coal ..	3,600 millions of tons.
5. From this deduct 1-3rd (as above) ..	2,400 ,, ,,
6. Deduct for quantity worked out 1-10th; and for waste 1-4th.	
7. Leaving for future use	1,620 ,, ,,

Which at the present rate of consumption would last for 1270 years.

This coal-field contains only 123 collieries, raising

(1857) 1,295,000 tons of coal; a quantity small when compared with the produce of South Staffordshire.

In the same year 520,000 tons of iron-ore were raised, nearly half of which was sent into the southern part of the county, and the remainder smelted in 20 blast furnaces, producing 130,560 tons of pig-iron.*

CHAPTER XII.

CHEADLE COAL-FIELD, STAFFORDSHIRE.

A SMALL, and but slightly productive coal-field stretches from the valley of the Churnet on the north-east, to the hills of New Red Sandstone, which stretch in a picturesque and abrupt semicircle along its southern borders. Towards this range the strata dip (S.S.W.), and on the north side of the Churnet the high moorlands of the Millstone Grit rise from beneath the Coal-formation. In the centre of the coal-field, an outlier of New Red Conglomerate reposes unconformably on the Coal-measures, and forms the site of the pretty town of Cheadle.†

The following is the succession of the coal-seams.

1. Two-yard coal.
2. Half-yard coal.
3. Yard coal.

* Mineral Statistics. 1858.

† See Geol. Survey Map, 72, N.E., and Horizontal Section, sheet 57, with "Explanation."

4. Littley coal.
5. Four-foot coal.
6. Woodhead 3-feet coal.

Hæmatite Bed of Churnet Valley.

The Lower Coal-measures of the Churnet Valley contain two thin coals, one of which has a roof of black shale with *Goniatites* and *Aviculo-pecten.** Below these there occurs a valuable bed of *iron ore,* which is now being extensively worked along the valley from the outcrop. This iron bed varies from 6 to 20 inches in thickness, is of a deep-red colour, and contains about 35 per cent. of iron. It seems to be in reality but shale highly impregnated with hydrated peroxide of iron.

CHAPTER XIII.

THE LANCASHIRE COAL-FIELD.

This great coal-bearing tract is very irregular in outline, and consequently difficult to describe. It may, however, be said to occupy a band of country lying east and west, sending offshoots at intervals into the Trias and Permian formations on the south, and into Lower Carboniferous strata which form its mountainous limits on the north. These offshoots are occasioned generally by enormous faults.

The extreme western boundary is a great fault, which, throwing down the New Red Sandstone on the west side,

* Mr. Binney, Trans. Geol. Soc., Manchester, vol. ii. p. 81.

ranges through Eccleston, Lathom Park, Bickerstaffe, Knowsley Park, and Huyton. To the northward the high moorlands, formed of Millstone Grit and Lower Coal-measures, traversed by deep valleys with scarped flanks, reach elevations of 2,000 feet, and stretch with a semi-circular outline from Chorley to Staleybridge by Bolton, Bury, and Oldham. From this elevated tract the country gradually descends towards the valley of the Mersey, and the Coal-measures dip under the Triassic and Permian strata, which form the low-lying districts, by Rainford, Newton, Ashton in Makerfield, Leigh, Astley, Eccles, Manchester, and Stockport, near which point the coal-field crosses the Mersey and enters Cheshire. The extreme length from Bickerstaffe to Staleybridge is 32 miles, and the average breadth 6 miles. Smaller isolated coal-fields occur at Croxteth Park, Manchester, and Burnley.

General Succession of Formations.

			Maximum Thickness. Feet.
Trias 4,750 ft.	Keuper	1. Red Marls (Cheshire)	3,000
		2. Lower Keuper Sandstone (Waterstones) ..	500
	Bunter	1. Upper Mottled Sandstone	500
		2. Conglomerate beds	650
		3. Lower Mottled Sandstone (often absent) ..	100

Note.—Several valuable memoirs on this coal-field have appeared by Mr. Binney, Trans. Geol. Soc., Manchester, vols. i. and ii., part 7., also by Mr. Bowman—*Ibid.* See also Mr. Dickinson's Vertical Section, in Report of the Inspectors of Mines for 1858. The Geological Survey of Lancashire is now in progress, and partly completed.

			Maximum Thickness. Feet.
Permian Series 355—650 feet.	1. Upper	Red marls and limestones of Leigh, Patricroft, Manchester, with *Schizodus*, *Bakevellia*, *Turbo*, *Tragos*, *Rissoa*, *Natica minima*	250
	2. Lower	Sandstone of Collyhurst, &c.	100 to 400
Coal-measures 6,800 ft.	1. Upper	Shales, sandstones, and limestones of Ardwick, with *Microconchus*, *Cyrene*, and fish of the genera *Ctenoptychius*, *Megalichthys*, *Palæoniscus*, &c.: below these beds are sandstones, shales, and thin coal-seams	1,500 to 2,000
	2. Middle	From the Worsley Four-feet Coal to the Flags below the "Arley Mine," with *Anthracosia*, *Modiola*, fish, &c.	3,000
	3. Lower, or Gannister Beds.	Flags, shales, and thin coals, with Gannister floors, and roofs of shale with *Spirorbis* *Goniatites*, *Nautilus*, *Avicula-pecten*, *Lingula*, *Anthracosia*, fish, *Cythere* or *Cypris*	1,800
Millstone Grit		From the "Rough Rock" to the lowest millstone grit (with thin coals)	3,500
Limestone Shale or Yoredale Rocks, with molluscs			2,000

The coal-series varies considerably in different parts of the districts, and there is a general thickening of the sedimentary materials, as sandstones and shales, towards the N.N.W. Thus the *same* coal-seams are farther apart

at St. Helens than at Prescot, and at Wigan than at St. Helens.

One coal-seam at least can be traced over the entire district under different names. At St. Helens it is the "Little Delf," at Wigan the "Arley Mine," the "Riley Mine" of Bolton, and the "Dogshaw Mine" of Bury. It is the lowest coal-bed of the middle coal-series, and one of great economic value. Its roof frequently contains fish remains, and some yards above it there occurs a very constant bed of ironstone filled with *Anthracosia robusta* (formerly called *unio*). Above this is the "Rushy Park" coal, which is very constant; but unfortunately the most valuable of all the coal-seams, the *Cannel Mine* of Wigan, thins away in every direction from Wigan as a centre.

General Section of the Coal-series at Wigan.

	Yards.	Ft.	In.
Strata .. .. .. (about)	100	0	0
Ince Yard Coal	0	3	0
Strata with ironstone	51	0	0
Ince Four-feet *Coal*	0	3	7
Strata	27	0	0
Ince Seven-feet (with parting)	0	7	0
Strata	23	1	0
Furnace Mine (with parting)	0	4	7
Strata	84	0	10
Pemberton Five-feet Mine	0	5	2
Strata	25	1	0
Pemberton Four-feet Mine	0	4	6
Strata	149	0	0
Wigan Five-feet (inferior)	0	4	6
Strata	21	0	0
Wigan Four-feet (inferior)	0	4	0
Strata, with a worthless coal called "Nine-feet Mine"	125	0	0
Cannel (best gas coal)	0	3	0

	Yards.	Ft.	In.
Strata (variable)	1	1	0
King Coal	0	3	10
Strata	79	0	0
Yard Coal	0	3	0
Strata	50	0	0
Bone Coal	0	2	3
Strata	3	0	0
Smith Coal (Rushy Park)	0	3	6
Strata	60	0	0
Arley Mine (the most valuable next to the *Cannel*)	0	4	0

The strata here enumerated are characterized by several bands with *Anthracosia.* From the *cannel,* Mr. Peace has collected splendid specimens of fishes belonging to the genera *Megalichthys*, *Holoptychius*, *Diplopteris*, *Ctenoptychius.*

The Lower Coal-measures, or Gannister beds, commence with the micaceous flagstones of Up-Holland, and contain six or seven coal-seams, seldom of greater thickness than 2 feet. Mr. Binney has shown that in various parts of the coal-fields all these coals contain *Goniatites*, *Nautili*, *Aviculo-pectens*, &c. in their roofs, species which do not pass upwards into the Middle Coal-measures; at the same time species of *Anthracosia* occur in these same beds at Billinge. The floor of one or more of these lower coals (called sometimes "Mountain Mines," from their occurrence in the uplands) is formed of a very hard siliceous rock with *Stigmaria ficoides*, called *Gannister*, from which the name, suggested by Professor J. Phillips, has been adopted for the whole series.*

In estimating the resources of the Lancashire coal-

* See Captain T. Brown, on "New Species of Fossil Shells," &c. Trans. Geol. Soc. Man., vol. i.

field, I shall altogether exclude these Gannister or lower coals, as they are too thin ever to admit of mining very far from the outcrop.

Iron Ores.—The Ironstone measures of Lancashire are on the whole very poor, and although formerly used for smelting at Haigh foundry, are only now employed at Kirkless Hall blast-furnaces, and that very sparingly.* At Patricroft the Upper Coal-measures yield a valuable calcareous hæmatite 2 feet thick, and Mr. Binney has identified this same band in the upper beds of the Manchester coal-field.

Faults.—The Lancashire coal-field is traversed by dislocations which, although of great magnitude, produce scarcely any perceptible features at the surface—so complete have been the effects of denudation in levelling down inequalities arising from the displacement of the rocks. Over the southern portion of the district many of the faults slope or *hade* considerably; the general inclination being 25° from the vertical, but often more.

The western boundary fault of the coal-field is a downthrow on the west of 1,500 yards east of Ormskirk, where the Lower Keuper Sandstone and Lower Coal-measures are brought into contact.

The Great Up-Holland fault, which brings up the Lower Coal-measures so as to form an elevated band of country between the coal-fields of Rainford and Wigan, has a throw of 650 yards east of Lord Crawford's collieries.

The Coal-measures at Wigan are divided into belts,

* These, I believe, are the only blast-furnaces at present erected in South Lancashire, and are supplied with hæmatite ore from Ulverston.

bounded by parallel faults which range N.N.W., having throws varying from 150 to 600 yards: of these the principal are the "Shevington fault," the "Cannel fault of Ince," and the "Great Haigh fault." Towards Manchester there is the "Great Pendleton fault," ranging along the valley of the Irwell (N.N.W.), bringing in the New Red Sandstone, with a downthrow on the N.N.E. of 1000 yards, as calculated by Mr. Binney. Lastly, the great fault along which the Manchester coal-field has been upheaved on the west against the New Red Sandstone; the throw being at least 400 yards. All these dislocations appear to have been produced, or at least *repeated*, after the period of the Trias.

Fossils.

Upper Coal-measures.—Fish of the genera, *Ctenoptychius*, *Megalichthys*, *Diplopteris*, *Palæoniscus*, *Platysomus*, *Diplodus*, and large bony rays resembling those of Burdie House in Scotland.* Crustacea: *Cythere ?* (Cypris) *inflata.* Annelides: *Spirorbis carbonarius.* Plants of the usual Coal-measure species.

Middle Coal-measures.—Fish: *Holoptychius*, *Platysomus*, *Palæoniscus*, *Cœlacanthus*, *Megalichthys*, *Diplopteris*, *Ctenoptychius*, *Diplodus.*† Molluscs: *Anthracosia* and *Modiola.* Plants: *Coniferæ*, *Lepidodendron*, *Sigillaria*, *Calamites*, *Halonia*, *Knorria*, &c., and ferns.‡

Lower Coal-measures.—Fish: several of those above-named. Molluscs: *Goniatites undulatus*, *Listeri*, *sphericus*,

* Binney. Trans. Geol. Soc. Manchester, vol. i.

† *Ibid.* "On the Fishes of the Pendleton Coal-field."

‡ Of these there are specimens in the Museum of the Geol. Society of Manchester.

reticulatus, mutabilis, calyx, &c.; *Orthoceras attenuatus, sulcatus; Nautilus carinatus; Aviculo-pecten papyraceus, Pecten dissimilis, Posydonia, Lingula, Modiola minuta, Spirifer Gloveri, filaria;* and *Productus* lying above one of the lower coals at Burnley.

Resources of the Lancashire Coal-field.

In estimating the resources, it will be necessary, as already stated, to discard from our calculations the lower coal-series with its thin coal-seams, as these, from their insufficient thickness, are never likely to warrant mining at greater depths than about 350 yards.

Secondly, it will be most convenient to limit the inquiry to the actual coal-field included between the *Arley Mine* and the highest Carboniferous strata of Pendleton (which lie about 330 yards above the *Worsley four-feet coal*), including in all 4000 feet of strata. All these beds dip under the newer formations towards the valley of the Mersey; and their depth may be calculated from the thickness of these formations, as given at the head of this chapter. (Page 101.)

1. Area of the coal-field (exclusive of the Manchester and Burnley fields) ..	192 square miles.
2. Total thickness of strata down to the Arley mine	4,000 feet.
3. Number of workable coals above 2 feet; St. Helens, 13; Wigan, 16; Pendleton, 18; giving an average thickness of	60 feet of coal.
4. Total original quantity of coal (corrected for denudation)	5,947 millions of tons.
5. Deduct for quantity already raised, 1-6th ..	4,956 " "
6. Deduct for waste, &c., 1-4th; leaving for future use	3,717 " "

Note.—For the calculation of the probable duration of this coal-field see p. 112.

THE MANCHESTER COAL-FIELD.

The north-eastern side and suburbs of Manchester stand upon a small coal-field, entirely enclosed by New Red Sandstone, except at Collyhurst, where it is in contact with Permian strata. The shape of this coal-field is oblong, with its longest diameter lying N. N. W., and about four and a half miles in length; in its broadest part it is about a mile and a half across.

South of the fault which crosses it north of Miles Platting, and throws in on the north side the Permian beds of Collyhurst, the dip of the strata is south-west. The highest beds consist of red clays, shales, sandstones, and three or four beds of limestone, with *Spirorbis*, &c., and two thin coal-seams. These strata can be traced along the banks of the river Medlock, at Ardwick. The fossils which they contain have already been described. Beyond question they are the finest representative series of Upper Coal-measures in the whole of Britain. Below these calcareous beds, there occurs a thick series of shales, sandstones, &c, with seven beds of coal, the thickness of which is only four feet. These coal-seams are probably on a parallel with the Worsley "four-feet" mine and its associated strata; but the thick coals, which lie about 1000 feet below this coal at Pendleton, have not yet been reached in the Manchester coal-field.

Iron Ore.—Mr. Binney, who has described this district with a fulness that leaves little to be required, has discovered in the bed of the Medlock a calcareous

hæmatite, occurring in large blocks, which he considers identical with the valuable ore now being worked at Patricroft.*

THE BURNLEY COAL-FIELD.

Situated some ten miles to the north of the main mass of the Lancashire coal-field, and connected by a mountainous tract of Lower Coal-measures and Millstone Grit, the small, but rich coal-basin of Burnley occupies a valley encircled by hills of these formations.

The outline of this coal-field is nearly oval; its longest axis, lying north-east and south-west, traverses Burnley. It is about seven miles in length and five in greatest breadth.

The eastern side of the coal-basin is bounded by a large fault, along which the Lower Coal-measures have been upheaved on the east side into high, terraced hills, while on the west side of the fault the productive Coal-measures plunge at high angles towards the centre of the basin. In this direction they gradually flatten; and at Burnley are perfectly horizontal. On approaching the opposite side of the basin, the dip rapidly augments; and along the base of Padiham Heights the strata rise to the surface in rapid succession.

There is one point of much interest in connection with this coal-field. A transverse section across the

* Binney "On the Geology of Manchester.—*Ibid*, vol. i.

Note.—My information regarding this coal-basin is derived from my friend Mr. Binney, and from a visit in company with members of the Geological Society of Manchester, at the invitation of Sir J. Kaye-Shuttleworth of Gawthorpe Hall.

ridges of Padiham Heights and Pendle Hill, in the direction of Clitheroe, gives in unbroken succession, a complete series of beds from the *Fulledge main coal,* or *Arley mine,* to the Carboniferous Limestone; and I believe it is the only spot in Lancashire where none of the links of this chain of rocks are absent.

This section includes:—1. The outcrop of the "Arley mine," under Padiham reservoir; 2. The Lower Coal-measures, or Gannister beds, with thin coal-seams; 3. The "Rough Rock" and the beds of Millstone Grit, the lowest of which forms the escarpment of Pendle Hill, 1831 feet in height; and 4. The Limestone Shale or Yoredale series passing downwards into massive encrinital limestone. The whole of this series reaches a thickness probably little short of 10,000 feet.

Succession of Coal-Seams at Burnley.

	Thickness. Feet.
Strata	30
1. *Doghole Coal*	6
Strata	21
2. *Kershaw Coal*	3
Strata	81
3. *Shell Coal* (Anthracosia)	2½
Strata	18
4. *Main Coal*	5
Strata	33
5. *Maiden Coal*	3
Strata, with 8 thin coal-seams	162
6. *Lower Yard,* or *Five-feet Coal* (with shales) ..	5
Strata	21
7. *Lower Bottom Coal* or *Four-feet Coal* ..	3½
Strata	78
8. Impure Cannel	2¼
Strata	21

			Thickness. Feet.
9. *Thin Coal*			$2\frac{1}{2}$
Strata			66
10. *Great Mine*	Coal	28 inches	4 (coal)
	Shale	12 "	
	Coal	19 "	
Strata			201
11. *China Bed*			2
Strata, with band of *Anthracosia robusta*			99
12. *Dandy Bed*			2
Strata			141
13. *Fulledge Main Coal* or *Arley Mine*			4

Lower Coal-measures, with Gannister coal, and two or three other seams with roofs containing Goniatites, Aviculo-pecten, &c.
Millstone Grit series, with several thin coals.

From this section it will be seen that, near the centre of the basin, there are 1017 feet of strata, down to the lowest thick coal, representing the *Arley mine* of Wigan, or the *Dogshaw mine* of Bury. There are about twelve workable coal-seams, with 40 feet of coal; and above the Fulledge main seam we find the bed of *Anthracosia robusta*, which occurs in the Wigan district above the Arley mine, and points to the identity of these two beds of coal.

Resources.

The basin-shaped structure of this coal-field has only recently been determined; and consequently towards the centre the lowest coals lie still undisturbed by the miner's pick, these seams having till recently been worked only near their outcrop. The upper seams occupy a comparatively small area; and without pretending to accuracy, we may assume the quantity already worked out at one-tenth of the whole.

The coals of the Gannister series are not included in the following estimates:—

1. Area .. .. 20 square miles.
2. Thickness of strata 1,017 feet, with 40 feet of workable coal.
3. Total original quantity (corrected for denudation) .. .. .. } 403 millions of tons.
4. Deduct for quantity worked out 1-10th.
5. Deduct for waste, &c., 1-4th.
6. Leaving for future use about 272 millions of tons.

The thin coal-seams of the Lower Coal-measures are worked at Church, Quarlton, and Darwen, and are spread at intervals over a large extent of the hilly districts beyond the boundaries of the middle or productive series.

General Summary of Resources of the Lancashire Coal-fields.

1.	Area of the main coal-field	192	square miles.
2.	„ Manchester coal-field ..	5	„
3.	„ Burnley coal-field ..	20	„
	Total	217	„

Quantity of available Coal.

4.	Main coal-field	3,717	millions of tons.
2.	Manchester coal-field	23	„ „
3.	Burnley coal-field	272	„ „
	Total	4,012	„ „

The quantity of coal raised in 1857 was 8,565,500 tons. Taking the future production at 9 millions of tons, there is sufficient coal to last for 445 years.

The above calculation includes the coal within a vertical depth of 4000 feet.

This coal-field contains (1857) 390 collieries—viz.: Lancashire, 359; Cheshire 31,—the latter producing 550,000 tons.

CHAPTER XIV.

CUMBERLAND COAL-FIELD.

The zone of Carboniferous rocks which wraps round the northern flanks of the Cumberland mountains is surmounted by the rich coal-field of Whitehaven, Workington, and Maryport. Between this last town on the north and St. Bees Head on the south, it stretches along the coast of the Irish Sea, and extends inwards for a distance of five miles, in which direction the beds rise and crop out. From Maryport the coal-field extends eastward to Bolton. Its total length is about 20 miles, and greatest width, at Workington, about 5 miles.*

From the Memoir of Professor Sedgwick, who has recorded the distinctive features of this coal-field, I gather the following descending series.†

Succession of Strata.

New Red Sandstone of St. Bees' Head, decomposing into grotesque and castellated forms.

Permian strata .. 1. Gypseous marls surmounted by sandy marls and micaceous sandstone.

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* Ruthven's Geological Map of the English Lakes.

† Trans. Geol. Soc., London, vol. iv. I have also been kindly assisted by Mr. Dickson, of Whitehaven, who has furnished several colliery sections and much general information.

Permian Strata ..	2. Conglomerate of magnesian limestone, &c., resting on an eroded surface of the Whitehaven sandstone.
	3.(?) Massive reddish sandstone of Whitehaven. Professor Sedgwick appears doubtful of the affinities of this rock—100 to 150 feet.
Coal-measures 2,000 feet* ..	1. *Upper*, most fully developed at Cleat Moor containing 7 workable coal-seams.
	2. *The Lower*, with 4 or 5 thin and inferior coal-seams.

1. Grits and limestone shales, with thin bands of coal at Hesket New Market.

Succession of the Coal-Seams.

Whitehaven.

	Thickness. Feet.
Strata	432
1. *Yard Band* (about)	3
Strata	30
2. *Coal*	2½
Strata, with a thin coal-seam	78
3. *Bannock Band*	8 to 9
Strata	60
4. *Main Band*	6 to 11
Strata	240
5. *Low Bottom Coal*	4

Workington.

Strata	132
1. *Fiery Band*	2
Strata	96
2. *Brassy Band*	2¼
Strata	72
3. *Cannel* or *Metal Band*	4 to 6
Strata	60
4. *Bannock Band*	5½
Strata	30
5. *Little Main Band*	3 to 4
Strata	180

* Mr. Dickson calculates this at considerably less.

	Thickness. Feet.
6. *Main Band*	9 to 10
Strata	210
7. *Yard Coal*	2 to 3
Strata	102
8. *Four-feet Coal*	4
Strata	150
9. *Udale Band*	3 to 4

At Maryport, beneath the Lower Red Sandstone, there occurs the "Ten-quarter coal," 7 feet thick, supposed to represent the "Bannock Band" of Workington, and the "Metal" and "Cannel bands," separated by 36 feet of strata, are considered to represent the "Main band."

The thick coals of Workington are thrown out south of that town by a large fault, upheaving the Lower Coal-measures, which occupy an extensive plateau, stretching from Harrington to the hills north of Moresby. Another great fault, with a downthrow on the south-west, again brings in the productive measures of Whitehaven. Unfortunately, however, between this fault and the village of Parton, the beds dip to the east, so that all the coal-seams below high-water mark crop out under the sea, and the coal cannot be extracted on account of the quantity of sea-water which finds its way along the planes of bedding. In some positions the coal has been followed more than a mile under the sea.

From Workington to Flimby, a large unwrought coal-field is supposed to exist, and from Workington to Maryport the general dip of the strata is north-west, and the coals crop out inland, where they have been worked to some extent in very early times.

From Maryport to Bolton, by Crosby and Aspatria, the coal-seams are overlaid by the newer strata of either Permian or Triassic age.

Resources.—Probably not more than one-fourth of the thick coal of this field remains to be extracted. Much of it has been destroyed by denudation. A smaller portion has already been exhausted, and a still smaller cannot be won on account of physical obstructions. We may thus sum up its capabilities for future supply:—

1. Area of middle productive measures	..	25 square miles.
2. Average thickness of workable coal ..	..	15 feet.
3. Quantity of coal originally	..	387 millions of tons
4. " " worked out and destroyed .		290 " "
5. " " remaining for use ..	..	97 " "

Which would last for about 100 years at the present rate of production.

In 1856 there were 32 collieries, raising 809,546 tons of coal.

CHAPTER XV.

WARWICKSHIRE COAL-FIELD.*

THIS is a small but rich coal-field, extending towards the south-south-east from a mile east of Tamworth, in a constantly narrowing band, by Atherston and Nuneaton, to near Wyken—a distance of 15 miles. At the northern end the strata form a trough four miles in breadth,

* For details of this coal-field see Mr. Howell's Memoir "On the Geology of the Warwickshire Coal-field, &c.," and the Maps and Sections of the Geological Survey. The section of the coal-field is reduced from No. 5, Sheet 51, by Mr. Howell.

bounded on the west, north, and east by large faults which bring in the New Red Sandstone. The Coal-measures dip under a large district occupied by Lower Permian rocks, extending under Coventry and Warwick. This tract, with an area of 90 square miles, is underlaid by coal at a depth not greater than 2500 feet in any part, often much less. At the south end of the coal-field the whole of the Coal-measures are overlapped by the New Red Sandstone, which passes across the edges of the beds and rests upon the Permian rocks. The prolongation of the coal-seams under the Trias has been proved for more than two miles.

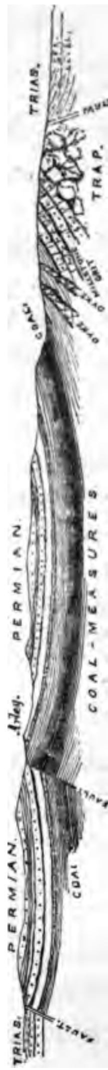


Fig. 13.—SECTION ACROSS THE CENTRE OF THE WARWICKSHIRE COAL-FIELD.
Length about 6 miles.
At Arley the outcrop of Limestone with *Spirorbis*.

General Succession of the Formations.

		Maxim. thickness Feet.
Trias.	1. Red Marl	600
	2. Lower Keuper Sandstone	180
	3. Bunter Sandstone, only sparingly represented.	
Lower Permian Rocks.	1. Brown and purple sandstones and marl, with calcareous breccia and conglomerate with *Stropholosia?* *Labyrinthodon*, and plants	2,000

		Feet.
Coal-measures.	1. Sandstones and shales, at the base of which, a band of limestone with *Spirorbis carbonarius*	50
	2. Coal-measures with 5 workable coals lying near the centre of the series	1,400
	3. Lower Coal-measures unproductive of coal, and traversed by dykes of greenstone ..	1,500
Millstone Grit.	1. Hard siliceous rock, with bands of shale, altered by intrusive greenstone (about)	500

Coal-seams.—The five workable coals lie about 1000 feet below the *Spirorbis* limestone. At the northern end of the district they are separated by about 120 feet of shales and sandstones, which all decrease in thickness while the coals remain nearly the same, and at Wyken, near Coventry, the five seams combine to form one bed of coal 26 feet in thickness. This is a change parallel to that which occurs in South Staffordshire in the case of the *thick coal,* which becomes split up northwards from Wolverhampton. Both cases exemplify in a remarkable degree the greater persistency of coal-beds over the sedimentary strata with which they are associated.

Resources.

1. Area of coal-field (beyond the boundary of the Permian rocks to the outcrop of the "Seven-feet coal")	30 square miles.
2. Thickness of coal	26 feet
3. Original quantity of coal (corrected for denudation)	627 millions of tons.
4. Deduct for quantity worked out, and loss 1-3rd ; leaving for future use ..	418 " "

Which at the present rate of consumption, 335,000 tons, would last for 1244 years.

Under the Permian Rocks there is about an equal

quantity of coal at a depth of less than 2500 feet, and about four times as much under 4000 feet. Mr. Howell's sections show the probability that the coal-seams lie very regularly, and nearly horizontally under this formation. I cannot, therefore, but regard as of peculiar value this vast reservoir of fuel lying at the borders of the south-eastern counties, and actually closer than any other coal-bearing district to the metropolis of Britain.

The Lower Coal-measures are traversed by several intrusive dykes of greenstone, which *nearly* correspond with the planes of bedding. These dykes have been injected subsequently to the deposition of the Coal-measures, as they have baked and blanched the shales with which they are in contact. At the base of these strata we find the Millstone Grit changed into quartz rock through the influence of a mass of greenstone upon which it rests. Beyond this the whole of the strata are broken off by a great fault, which introduces the Trias.

CHAPTER XVI.

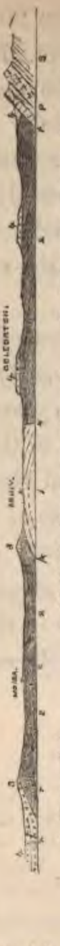
THE LEICESTERSHIRE COAL-FIELD.

This small but valuable coal-field occupies an irregularly-shaped district south of the Valley of the Trent. Along its western, northern, and southern sides, it is

Fig. 14.—SECTION ACROSS THE LEICESTERSHIRE COAL-FIELD.

Distance about 12 miles.

WEST. EAST.



4. Keuper Beds. 2. Middle Coal-measures, with coal. P. Pophyry { Cambrian Rocks of
3. Bunter Conglomerate. 1. Lower Coal-measures, S. Slate, } Charnwood Forest.
× Faults.

bounded by strata of the age of the Trias; and along the north-east, by the ancient slates and porphyries of Charnwood Forest, which form a miniature mountain range, rising in rugged knolls and serried ridges above the general level of the country. The Coal-measures underlie the New Red Sandstone, to a large and unknown distance, towards the south and west; and in the Coleorton district, several collieries are situated upon the Keuper Marl, and pierce this formation downwards to the coal beneath the deepest of these shafts is at Bagworth colliery.

The coal-field is physically divisible into three districts—that of Moira, on the west; Ashby-de-la-Zouch, in the centre; and Coleorton, on the east. The central district is formed of LowerCoal-measures,

Note.—This coal-field has been very ably illustrated by Mr. Mammatt, in his "Geological Facts," and more recently by the works of the Geological Survey, consisting of Maps 63, N.W., 71, S.W.; Horizontal and Vertical Sections; and a Memoir "On the Geology of the Leicestershire Coal-field," by the Author, 1860.

without workable coals, and is bounded on both sides by down-cast faults, which introduce the workable coal-beds of Moira and Coleorton. The coal-series of these latter districts cannot be identified with each other, though they are probably synchronous. The "main-coal" of Moira is from twelve to fourteen feet thick; that of Coleorton, from six to eight feet.

General Succession of Formations—Leicestershire.

		Thickness.
Trias ..	Keuper series	700 ft.
	Bunter, (sometimes absent)	200 „
Permian Rocks	Breccia, sparingly represented.	
Carboniferous Series	1. Middle Coal-measures, with about 20 coal-seams, of which 10 are workable	1,500 „
	2. Lower Coal-measures, unproductive ..	1,000 „
	3. Millstone Grit	50 „
	4. Yoredale series and Carboniferous Limestone.	

The following is a list of the coal-seams in both the Moira and Coleorton districts.

Coal-seams of the Leicestershire Coal-field.

Moira District—(West.)	Ft.	In.	Coleorton District—(East.)	Ft.	In.
Ell Coal (*b*)	3	8	Stone smut (*c*)	4	9
Dicky Gobbler (*b*) ..	3	6	Swannington (*a*)	3	7
Block Coal (*a*)	3	6	Slate-coal (*b*)	4	8
Little or Four-feet (*a*) ..	4	6	Coal	2	10
Cannel (*b*)	3	6	Coal	3	7
Main {Over / Nether} variable ..	12	0	Main-coal (*a*)	6	0
			Upper Lount (*b*)	3	9
Toad (*c*)	3	6	Second Lount (*b*) ..	3	0
Little Woodfield (*c*) ..	2	6	Middle Lount	4	6
Woodfield (*b*)	5	0	Nether Lount	4	6
Stockings (*c*)	9	0	Heath End Coal & Cannel	13	0
Eureka (*a*)	4	6	Lower Coal-measures.		
Strata below this unproved.					

In the above list, I have omitted several of the least important coals. The letters *a*, *b*, *c*, indicate the degrees of quality.

I shall conclude this account of the Leicestershire coal-field by stating a few geological facts of interest.

Igneous Rocks.—At Whitwick, a remarkable *bed* of "whinstone" or greenstone, intervenes between the Coal-measures and the New Red Sandstone. In one of the shafts of Whitwick colliery it is 60 feet thick, and has turned to cinders a seam of coal with which it comes in contact. It has evidently been poured out as a sheet of lava over the denuded surface of the Coal-measures at some period prior to that of the Trias.

Rock-faults.—In the same district, the main-coal has been extensively invaded by channels filled up with fine sand, which completely replace the coal over several hundred yards. One of these banks of sandstone, at Pegs-green colliery, was found to be 80 yards in width. It is composed of the same sandstone that forms the roof of the coal itself. In another of these, south of Whitwick colliery, a tunnel was driven to a distance of 110 yards without passing through it. These phenomena are similar to those already described in the case of the coal-field of the Forest of Dean.

Salt-water.—In the main-coal of Moira, especially in the Bath colliery, at a depth of 593 feet, salt-water, beautifully clear and of nearly the same composition as sea-water, trickles down from the fissures where the coal is being extracted. The brine is carried to Ashby de la Zouch in tanks, and is considered highly beneficial in scorbutic and rheumatic affections.

Resources.

1. Area of coal-field	15 square miles.
2. Number of workable coals above 2 feet ..	10, with 13 yards of coal.
3. Total original quantity of coal	302 millions of tons.
4. Deduct for quantity raised one-half, spoiled one-third, leaving for future use ..	50½ " "
6. But the quantity under the New Red Sandstone at a depth under 3000 feet is at least double the above quantity, making a total of	150 " "

Which at the present rate of production, 699,000 tons, would last 215 years.

In the Leicestershire coal-field there are 14 collieries, five of which work the coal under the New Red Sandstone. There are at present no iron-furnaces.

Fossils.—The plant-remains are abundant, and have been figured in Mammat's "Geological Facts." The only shells are of the genus Anthracosia; and of crustacea—*Cythere*, or *Cypris*.

CHAPTER XVII.

DERBYSHIRE AND YORKSHIRE COAL-FIELD.

This great field, though forming parts of the shires of Derby, Nottingham, and York, is physically *one;* and in treating of its structure and resources we must ignore political and social landmarks. It is the largest coal-field in England; and about 150 square miles smaller in area than that of South Wales.

Fig. 15.—GENERAL SECTION ACROSS THE DERBYSHIRE AND YORKSHIRE COAL-FIELD.
Drawn along the border of the two counties into Notts.
Distance 25 miles.

1. Trias. 2. Magnesian Limestone, &c. 3. Coal Measures with coal. 4. Millstone Grit. 5. Yoredale Rocks. 6. Carboniferous Limestone.

Its eastern boundary is the escarpment of the Magnesian Limestone, with its subordinate Lower Permian strata, which, commencing near Nottingham extends northwards beyond the limits of the coal-field itself. Upon reaching the crest of the escarpment, you find yourself on the edge of a table-land, resembling that of the Oolite of Gloucestershire, but less lofty. One point of this ridge is crowned by the turrets of Bolsover Castle. The southern boundary is New Red Sandstone, and the strata rise and crop out westward as far north as Bradford and Leeds, where they bend round to the east, and finally disappear under the Magnesian Limestone, which passes over and rests directly on the Millstone Grit. The greatest length of the coal-field from south to north is 66 miles; and its breadth varies from five to twenty miles. Though the general dip of the strata is eastward, there generally occurs along the centre of the field a gentle undulation (shown in the section, fig. 15), which for a certain distance produces a westerly dip; but the strata always roll over when

approaching the base of the Permian rocks. The Coal-seams are only occasionally broken by faults.

To the westward, the Lower Carboniferous series rise into the lofty ranges of the Pennine chain, forming a natural division between the counties of Stafford and Lancashire on the west, and Nottingham and Yorkshire on the east, as well as their respective coal-fields. In fact, the upheaval of the Lower Carboniferous rocks, has rent asunder a coal-field which originally stretched across from Stafford and Cheshire to Nottinghamshire and Yorkshire.

The loftiest escarpment of this central chain is Mickle Fell, formed of Millstone Grit, 2600 feet, and the Carboniferous Limestone of Derbyshire reaches an elevation of 2533 feet.*

Succession of Strata.

Southern Extremity—Derbyshire. The succession of strata along a line drawn from Kirkby Woodhouse through Alfreton Common and Wingfield Manor to Crich, may be very clearly ascertained, both from the details of the collieries, and the natural sections which present themselves. The following is the series in descending order.

		Feet.
Permian Rocks.	1. Marls and sandstone	40
	2. Magnesian limestone	60
	3. Marls and sandstone	30

* See Professor Phillips' "Geology of Yorkshire," where the physical features of the Pennine chain are graphically portrayed; also Mr. Denny's "Fossils of the Yorkshire Coal-field," Proc. Geological Society, Yorkshire, vol. ii.

		Feet.
Middle Coal-measures 2,500 ft.	Strata to Top Hard coal, about ..	700
	Waterloo coal; Ell; Lower Hard; Furnace; Black Shale or Clod; Kilburn; Shales	1,600
Lower Coal-measures or Gannister series.	Flagstones of Wingfield Manor. Shales and flaggy sandstones, with two coals underlaid by Gannister floors	1,000
Millstone Grit	Rough rock. Flags and shales. Hard millstone	350
Limestone Shale, or Yoredale Rocks		250

The Black Shale coal represents the "Arley mine" of Lancashire; and the Kilburn coal, the "Low Moor coal" of Yorkshire. In the lower beds there are several valuable ironstones, filled with *Anthracosia*. The whole series is very thin when compared with their representatives in Lancashire.*

For the purpose of affording a comparison of the formations towards the north and south of the field, I select sections from Nottinghamshire, and Barnsley in Yorkshire.

* Horizontal Section of the Geol. Survey, Sheet 60. The author is much indebted to Mr. Bean, manager of the Butterly Company's Works, for assistance and information.

General Section of Strata.

Nottinghamshire*.—(Shireoak Colliery.)		Ft.
Permian Rocks.	Upper Permian marls and sandstone	56
	Magnesian limestone	102
	Lower Permian sands and shale	38
Strata, with beds of hæmatite and ironstone ..		42
The Manor Coal		2
Strata, with several thin coals		706
Shireoak or *Melton*, or *Baelbro' Hall Coal* ..		4¼
Strata, with an inferior coal, 3/2		120
Furnace Coal		2¾
Strata		138
Hazles Coal		3
Strata		238
Top Hard Coal (or *Barnsley Coal*)		3¾
Strata		
Dunshill Coal		2¾
Strata		
Waterloo Coal		4½
Strata, with 2 coals, two feet each		
Soft Coal		3½
Strata		
Lower Hard Coal ..		4

Barnsley, Yorkshire.†	Ft.
Magnesian limestone ..	75
Lower Permian sandstone ..	54
Ackworth rock	54
Strata	510
Shafton Coal	5
Strata, principally sandstone (Chevit rock)	393
Muck Coal	3½
Strata	219
Woodmoor Coal	3
Strata with half-yard coal .	45
Winter Coal	4
Strata	
Beamshaw Coal	3
Strata, with Kent Coal 1 foot, and Mapple Coal 4½ feet (inferior quality)	
Strata	216
Barnsley Coal	9¼
Strata	198
Swallow Wood Coal	3
Strata	234
Joan Coal	2
Strata	60
Flockton Top Coal	3¼
Strata	120

* Partly taken from section of Shireoak Colliery by Messrs. Lancaster and Wright. Journ. Geol. Soc., vol. xvi., p. 138.

† Rev. W. Thorpe, Section of Strata.—*Ibid.*

General Section of Strata—continued.

Nottinghamshire.	Ft.	Barnsley, Yorkshire.	Ft.
Strata		*Park Gate Coal*	5
Piper Coal	2¼	Strata	78
Strata		*Thorncliffe thin Coal* ..	2½
Furnace Coal	4	Strata	123
Strata		*Four-feet Coal* (variable) ..	2½
		Strata	108
Clod Coal (*with partings*) ..	6	*Silkstone Coal*	5
Strata	480	Strata	195
Kilburn Coal	5	*Whinmoor* or *Lowmoor Coal*	2½
Strata (with ironstone) ..	350	Strata .. .. (about) ..	150
Furnace Coal	2½		
Strata (principally shales)	150?		
Lower Coal-measures.–Flagstones, shales, and the coals with Gannister, thickness rather uncertain (about) ..	300	*Gannister flagstone* (about) ..	36
		Strata, principally shales ..	495
		Halifax Coal, (with *Pecten papyraceus* in the roof) and a floor of Gannister ..	1¾
Millstone Grit.		Strata (shales and flags) ..	81
		Halifax soft Coal	1½
		Strata	150
		Millstone Grit.	

In Derbyshire the principal coals are the "Top hard", and "Lower hard" seams, producing the valuable splint-coal, and in Yorkshire the most remarkable are the "Silkstone" and "Barnsley thick coals." The former is undoubtedly identical with the "Arley mine" of Lancashire, and thus this fine bed of coal, which seldom exceeds five feet in thickness, has originally spread over a tract embracing not less than 10,000 square miles!

In the Lower Coal-measures or Gannister beds, de-

scribed originally by Professor Phillips,* one or more of the coals, with their roofs of black shale filled with *Aviculo-pecten papyraceus*, *Goniatites*, *Posidonia*, &c., can be identified with those which range over North Lancashire: all of which facts go to prove the original continuity of these great coal-fields.†

Fossil Remains.—These have been summed up by Mr. Denny ‡ as consisting of 17 species of fish (placoid and ganoid). Of molluscs, 5 cephalopods, 17 conchifers and brachiopods. Crustacea, *Cythere* (Cypris). In the roofing-shale of several of the coal-beds fish remains occur, and so plentifully in the case of one of these, at Middleton, that the miners call it the "fish-coal." In the roof of the "Halifax coal," of the Lower Coal-measures, *Goniatites Listeri* is found throughout its entire course, sometimes beautifully preserved in iron pyrites, and with this is associated *Aviculo-pecten papyraceus*.

In the "Catherine Slack coal" near Halifax, *Nautilus Rawsoni* and *Orthoceras Steinhaueri* are frequent.

In the Middle Coal-measures there are bands of ironstone filled, over a great extent of country, with *Anthracosia* (Unio) and *Cythere* (Cypris).

The Coal-measures under the Permian and Trias. I have already stated that the whole of the coal-field dips at a very small angle beneath the escarpment of the Magnesian Limestone; and there is probably as large an extent of area below this formation as beyond its west

* Article "Geology," in *Encyclopedia Metropolitana*.

† See Mr. Binney, Trans. Geol. Soc., Manchester, vol. ii., part 7.

‡ Proc. Geol. Soc., Yorkshire, vol. ii.

erly limits. The greatest thickness of the Permian beds is shown in the section of Shireoak colliery to be 200 feet, as the shaft commences at the base of the New Red Sandstone;* and as the depth increases very gradually eastward, the "Shireoak" and "Top hard" coals must occupy a very large extent of ground at a less depth than 1000 yards, though the diminished thickness of the latter at Shireoak shows a general tendency to thin away towards the east. In Yorkshire there does not appear to be any tendency to an easterly thinning out of the coal-seams; but they usually *rise* towards the north-east, near to and under the Magnesian Limestone.†

Iron Ores.—There are several courses of valuable ironstones in this coal-field, supplying about 50 blast furnaces, yielding in the West Riding 96,200 tons of pig-iron, and in Derbyshire 106,960 tons. In addition to these the Cleveland ores, which are derived chiefly from the Middle Lias, yielded in 1857 upwards of one million of tons.

Resources.

In estimating the resources of this coal-field I include only the workable seams of the Middle Coal-measures; the coals of the Gannister series, though frequently of good quality, being too thin to be worked at depths much greater than 300 yards.

* As I am informed by my colleague, Mr. W. T. Aveline.

† As I am informed by Mr. Charles Morton, H. M. Inspector, to whom I am indebted for information regarding this coal-field.

1. Area of coal-field (not including that portion underneath the Magnesian Limestone)	760 square miles.
2. Greatest thickness of productive coal-measures (from the Ackworth rock above the Shafton coal to the Low Moor coal)...	2,500 feet.
3. Average number of workable coals above 2 feet, 15; giving a vertical thickness of coal	46 "
4. Total original quantity of coal (corrected for denudation)	17,656 millions of tons
5. Deducting 1-4th for the quantity worked out, and 1-4th for waste, &c., we obtain for future use	8,828 " "
6. This at the present rate of consumption of 12,563,000 tons, would last 702 years.	
7. The area, overspread by Permian (Magnesian Limestone) and Trias, under which several of the workable coals lie at a depth within 4,000 feet, is about 400 square miles, containing	12,390 " "
8. Total quantity of coal under 4,000 feet is therefore 12,390 + 8,828	21,218 " "

This coal-field supports 541 collieries, producing (1857) 12,562,882 tons of coal, which may be thus arranged:—

Derbyshire and Notts.	194	collieries	3,687,442	tons of coal.
Yorkshire ..	347	"	8,875,440	" "

Mr. Morton informs me that there are only about five collieries in Yorkshire working coal under the Magnesian Limestone, at which, in 1858, about 200,000 tons of coal were raised.

CHAPTER XVIII.

GREAT NORTHERN COAL-FIELD OF DURHAM AND NORTHUMBERLAND.

THE general succession of the strata and their relative position over the area of this coal-field is similar to that of Yorkshire, so that one section will serve to illustrate the structure of both. I must therefore beg the reader to refer to the transverse section at the commencement of the last chapter (fig. 15, p. 124).

The great northern coal-field extends from Staindrop, near the north bank of the Tees, on the south, to the mouth of the Coquet, where it enters Alnmouth Bay, on the north, the distance being nearly 50 miles. Its greatest diameter is near the centre, along the course of the Tyne, which forms the great highway for the export of coal to the London market.*

From the Coquet to the Tyne the North Sea forms the limits of the coal-field. South of this the escarpment of the Lower Permian Sandstone and Magnesian Limestone forms the boundary at the surface; but the Coal-measures underlie these newer rocks, and since Dr. William Smith,† first on theoretical grounds and afterwards by actual experiment, demonstrated the existence of the coal-field at Haswell near Durham,

* I have calculated the area of this coal-field from Mr. W. Oliver's map in the *Mining Record* office. There are some interesting details in "Our Coal and our Coal-pits," published by Messrs. Longman.

† About half a century ago.

both the Triassic and Permian formations have been perforated over a large area, especially at Seaham and Ryhope in Durham. The general dip of the strata is easterly as far as the margin of the sea, where they are almost horizontal.* The Permian strata are unconformable to the Coal-measures; and from the mouth of the Tyne southwards they rest successively on lower beds, till, at the south end of the coal-field, they finally overlap the whole coal-series, and for a distance of 48 miles (from the bank of the Tees to the margin of the Yorkshire coal-field) repose directly upon Millstone Grit and Yoredale Rocks.

From below the coal-field of Durham and Northumberland the Lower Carboniferous rocks rise towards the west and north into swelling moorlands, and ultimately into the mountainous tract of the Pennine chain, attaining, at Hedge Thorpe a height of 2347 feet, and at Yevering Bell, 2000 feet.

General Series of Formations.†

New Red Sandstone.—*Red sandstone* and conglomerate.

Permian Rocks† (Magnesian Limestone) 500 to 600 feet	1. Upper Permian marls, with gypsum	100 ft.
	2. Crystalline limestone, with *Schizodus Schlotheimi*, and *Mytilus septifer*.	
	3. Brecciated limestone (Tynemouth Cliff), lying on—	
	4. Fossiliferous limestone, with *Productus*, *Strophalosia*, *Athyris*, *Avicula*, &c., and numerous bryozoa.	

* As I am informed by Mr. M. Dunn, H. M. Inspector, to whom I am indebted for much information.

† From the works of Professor King and Professor Sedgwick.

Permian Rocks.	5. Compact limestone, with similar fossils.	
	6. Marl slate, calcareous shales and thin-bedded limestone, with fishes of the genera *Palæoniscus*, *Acrolepis*, *Platysomus*.	
	7. Lower Permian sandstone with gypseous marl	200 feet
Coal-Measures. 2,030 ft.	1. Upper series, with thin coals, and a band of ironstone with *Anthracosia*	900 "
	2. Middle series. From the "High Main Coal" to the "Low Main Coal"	430 "
	3. Lower Coal-measures, with 2 beds of coal, between 2 and 3 feet thick	700 "
Millstone Grit.	— Coarse grits and shales	414 "
Yoredale Rocks.	—Shale, with bands of limestone and thin coals	540 "
Scaur Limestone.*	—Ten beds of limestone, parted by as many beds of shale, containing coal-seams in Northumberland, upwards of	1,120 "

Coal-seams.†—The most important coal in the Newcastle district is the "High main" or "Wallsend" seam. It is the highest workable coal, and varies from 5 to 6 feet in thickness. It is traversed by the "90-fathom" dyke, and is persistent in its general character to its northern and western outcrop, but southward towards the valley of the Wear is split up into two seams by the intercalation of sandstone and shale.

The "Bensham" seam, 20 fathoms below the "High Main," is very variable in its qualities, and is often unworkable. It acquires its chief value towards the east.

* Professor Phillips' "Manual of Geology," p. 163.

† For the details of the coal-seams, I am indebted to Mr. Dunn, H. M. Inspector of Collieries.

and is worked extensively under the Magnesian Limestone at Sunderland. Its general thickness is 6 feet.

The "Low Main" seam is known to range from Widdington on the north to Ferry Hill on the south, a distance of about 40 miles. This coal, south and west of Newcastle, is moderately soft, and excellent for household use and coking. But passing northwards its character changes; it becomes very hard and less gaseous, and constitutes the most important bed of steam-coal. Below these lie several other seams, which will become more extensively worked as the supply from the valuable beds above described becomes curtailed.

The following is a list of the general series of coal-seams, for which I am indebted to Mr. Dunn.

Coal Series of Northumberland and Durham.
(Newcastle District.)

	Ft.	In.
Upper Coal-measures	900	0
1. *High Main Coal*	6	0
Strata	33	0
2. *Metal Coal*	1	6
Strata	33	0
3. *Stone Coal*	1	6
Strata	63	0
4. *Yard Coal*	2	10
Strata	63	0
5. *Bensham Coal*	2	10
Strata	78	0
6. *Five-quarter Coal*	3	0
Strata	48	0
7. *Low Main Coal*	6	0
Strata	60	0
8. *Crow Coal*	2	10
Strata	24	0
9. *Five-quarter Coal*	3	8
Strata	30	0

	Ft.	In.
10. *Ruler Coal*	1	10
Strata	96	0
11. *Townley* or *Harvey Coal*	3	1
Strata	42	0
12. *Jelly Coal*	2	2
Strata	42	0
13. *Stone Coal*	2	5
Strata	18	0
14. *Five-quarter Coal*	3	4
Strata	30	0
15. *Three-quarter Coal*	2	6
Strata	54	0
16. *Brockwell Coal*	2	11

The series below the Low Main coal are taken at Blaydon and Wylam, as they have never yet been worked at Newcastle.

Basaltic Dykes.—The coal-field is traversed by several basaltic dykes, generally ranging east and west, and running for several miles in nearly straight lines. The beds of coal on approaching these dykes become anthracitic, and ultimately worthless. Near Newcastle one of these dykes is also a fault, with a downthrow to the south of 90 fathoms; it coincides with the valley of the Tyne, and enters the sea north of Tynemouth. The Cock-field Fell Dyke, in South Durham, ranges from W. N. W. to E. S. E. There is also a natural system of fissures, called "cleats," ranging N. N. W.

Resources.

In estimating the extent of this coal-field, we must include not only the superficial area formed of the Coal-measures, but also the district overspread by the Magne-

sian Limestone and New Red Sandstone, as far south as the Valley of the Tees, there being no doubt whatever that most of the coal beds are accessible under this area at a depth under 4000 feet. In the following estimates, I shall give the resources of each separately, as well as conjointly.

Actual Coal-field beyond the Magnesian Limestone.

1. Area	460 square miles.
2. Number of workable seams above two feet about 10, with thickness of	36 feet of coal.
3. Original quantity of coal (corrected for denudation)	8,548 millions of tons.
4. Deducting for quantity worked out, 1-4th, and waste, 1-4th, there remains for future use	4,274 " "

Quantity under the Permian and Trias.

5. Area, under 4,000 feet	225 square miles.
6. Thickness of workable coal	24 feet.
7. Quantity for future use, after deducting for waste, &c.	3,158 millions of tons,
8. Total quantity under 4,000 feet of depth 3,158 + 4,274 = ...	7,432 " "

9. This, at the present rate of consumption (about 15,900,000 tons) would last for 466 years.

This coal-field contains 268 collieries, producing (1857), 15,826,525 tons of coal.

There are also 69 furnaces; of which 41 were in blast in 1857. Of these, 18 are in Northumberland, 51 in Durham. Total produce of iron, 347,750 tons.

Mr. Fordyce, in his work just published (1860), gives two estimates of the area: one of 840 square miles (p. 9), the other 750 (p. 31). It will be observed that this latter closely agrees with that arrived at by the Author (Appendix H). For further details see "Synopsis of the Newcastle Coal-field," by Mr. Buddle, Trans. Nat. Hist. Soc., Northumberland, vol. i.

CHAPTER XIX.

SUMMARY OF RESOURCES—ENGLAND AND WALES.

THE following table will exhibit at a glance the results arrived at, as stated in the previous chapters:—

Name of Coal-field.	Area Sq. Miles	Quantity of Coal to a depth of 4,000 ft.	Under Newer Formations to a depth of 4,000 feet. Area sq. miles.	Under Newer Formations to a depth of 4,000 feet. Quantity of coal to a depth of 4,000 feet.
		Millions of tons.		Approximate Millns. of tons
1. Anglesea	9	inconsiderable	..	..
2. Bristol and Somerset	45	747	105	1,742
3. Coalbrook Dale ..	28	28	..	..
4. Cumberland ..	25	97	..	..
5. Denbighshire ..	47	490	20	413
6. Derby and Yorkshire	760	8,828	400	12,390
7. Durham & Northumberland	460	4,274	225	3,158
8. Flintshire	35	21	uncertain	..
9. Forest of Dean ..	34	561	..	..
10. Forest of Wyre ..	..	inconsiderable	..	..
11. Lancashire	217	4,012	25	500
12. Leicestershire ..	15	50	30	401
13. North Staffordshire .	75	1,620	20	619
14. South Staffordshire.	93	973	..	..
15, Shrewsbury	..	inconsiderable	..	..
16. South Wales ..	906	16,000	..	..
17. Warwickshire ..	30	418	107	1,767
Total ..	2,779	38,119	932	20,990

Total area containing coal to a depth of 4,000 feet, 3,711 square miles.

Total available quantity of Coal within this depth 59,109 millions of tons.

Taking the annual produce of England and Wales at 60 millions of tons (the actual produce is 57 millions; but 3 millions may well be allowed for the increase of future years), the above supply of coal will last for about 1000 years.

If the above results can only be regarded as approximately accurate, and considering the nature of the inquiry they can scarcely pretend to more, they are at least sufficient to show, that for many generations to come, the mineral resources of England are capable of bearing any drain to which they can possibly be subjected either for home or foreign consumption.

CHAPTER XX.

GREAT SCOTTISH COAL-FIELD.

It will be observed, on looking at a geological map of Scotland, that the series of formations of which that country is composed are arranged in bands crossing the island from south-west to north-east; and, on the whole, parallel to the central range of the Grampian Hills.

The great coal-field of Scotland forms one of these bands, stretching from sea to sea, and occupying a trough between the southern slopes of the Grampians on the one side, and the northern flanks of an elevated district, composed of Old Red Sandstone and Lower Silurian rocks, stretching from Kirkcudbrightshire to Berwick, of which the Lammermuir, Pentland Hills, and

the highest sources of the Tweed form a part.* The western margin of the coal-field is washed by the Firth of Clyde, along the coast of Ayrshire; the eastern limit is the North Sea, from St. Andrews Bay, along both banks of the Firth of Forth, to the mouth of the Tyne. The northern limit passes from Ardrossan, by Glasgow, Stirling, and Cupar. The southern boundary is extremely irregular, deeply indented by promontories of Old Red Sandstone, and enormous protrusions of trap; but, on the whole, extends from Ayr to near Dunbar, along the flanks of the Lead Hills and Lammermuir Range. The extreme length, from the coast of Ayr to Fifeness, is 94 miles; the average breadth, 25 miles.†

Geological Age of the Scottish Coal-field.—Though it is by no means improbable that there are certain portions of the higher strata contemporary with the Coal-formation of central England, yet the great mass of the formation belongs beyond all question to the period of the Carboniferous Limestone. If we observe the gradual change which the Lower Carboniferous rocks undergo in their extension from the Midland counties of England into Northumberland and South Berwickshire, we shall be prepared for this remarkable change in their mineral character as developed in Scotland. In Derbyshire this Limestone formation consists of an enormous mass of

* Reaching at Broadlaw Hill, 2741 feet, and at Blackhouse Heights 2370 feet.

† The actual workable coal-surface is variously computed by Professor Rogers, Mr. Bald, and Mr. J. Nichol, not to exceed from 1500 to 1720 square miles.

calcareous rocks, once deposited in a sea teeming with animal life, almost devoid of sedimentary material, and entirely destitute of coal. Further north, in Lancashire and Yorkshire, thin beds of coal are found at a stage earlier than the true Coal-measures, associated with fossils allied to those of the Carboniferous Limestone. Still further northward, the bold coasts of Northumberland exhibit the Carboniferous Limestone rocks, opening out into different courses, and including thick beds of shale with several coal-seams; one of the calcareous bands, near the centre of the group, being characterized by *Posydonomya Becheri*—a fossil belonging to the Calp in Ireland and the Culm limestone in Devonshire.* These changes, carried to a still greater extent by the augmentation of sedimentary strata, such as shales and sandstones, and the increase in number and thickness of the beds of coal, introduce us into the great coal-formation of Scotland, which is composed of an assemblage of sandstones, shales, ironstones, and coal-seams, overlaid by beds of marine limestone, containing fossils of the period of the Carboniferous Limestone of England.

Trap Rocks.

The base of the coal-formation of Scotland is the Old Red Sandstone; and at or near the junction there has been a very general outpouring of submarine lavas, which we now find consolidated into greenstone, felspar-porphyry, and tufa, in some places earthy and amygdaloidal. These are stated by Sir C. Lyell to constitute a ridge parallel with the Ochils, extending from Stirling

* Murchison's "Siluria," p. 311.

to near St. Andrews, where they are very clearly exposed in the coast cliffs.* These bedded igneous rocks receive their highest exemplification in the bold escarpments of the Pentland Hills, Salisbury Crag, and the rock of Edinburgh Castle. The really stratified character of these rocks has only recently been demonstrated by my colleagues, Messrs. Geikie and Howell, and is beautifully indicated in the new geological map of Edinburgh. It is here shown that they follow the dip and direction of the associated strata, all pointing to the conclusion that they have originally been poured out over the bed of the sea, at intervals, during the deposition of the Lower Carboniferous strata. Rocks of a similar origin occur amongst the Braid Hills, Garlton Hills, as also in South Berwickshire; and probably include many of the great protrusions, which are found at intervals along the whole course of the Scottish coal-field, from the mouth of the Firth of Forth to the coast of Ayrshire. They may always be distinguished from eruptive traps by their bedded character; and, as a general rule, the strata which overlie them are not altered or metamorphosed, as when brought in contact with eruptive dykes.

In contradistinction to these are the dykes of later date, injected along fissures in the strata, in which they produce well-marked changes; such as expelling the bituminous part of coal, and hardening sandstones

* "Elementary Geology," p. 561. One of the most remarkable forms which these rocks assume along the coast, is known as the "Rock and Spindle." It consists of a pinnacle of tuff which may be compared to a distaff, and near the base is a mass of columnar greenstone, in which the columns radiate from the centre like the spokes of a wheel. Readers of Burns will recollect that "the rock" is the Scotch name for a distaff.

and shales. Three dykes of this nature are mentioned by Mr. Milne, in the coal-fields of Mid-Lothian, called "the Niddry dyke," "the Morison's-haven dyke," and "the Cockenzie dyke."

General Succession of Coal Series.

The Lothians.—The thickness of the coal-series in the Lothians, according to Mr. Milne, is from 1000 to 1050 fathoms; in the better-known portions of which, 286 fathoms consist of sandstone, 188 of shales, 27 of limestone, 21 of coal, and 12 of clay. There are from 50 to 60 coal-seams of greater thickness than one foot—the thickest being 13 feet.

The principal coals are "the Great Seam," which has been traced from its outcrop at Gilmerton, under the valley of the Esk, over the Carberry ridge, to the valley of the Tyne, a distance of 12 miles. It extends from the flanks of the Lammermuir range, northward to the sea. Below this, at a depth of 250 fathoms, is the "North Greens" coal, which yields the "Parrot-coal," valuable for its gas.

The "Boghead coal," in the county of Linlithgow, the object of a celebrated trial at law, and one of the most valuable of the brown cannels of Scotland, occurs in a small area, and is of an average thickness of 18 inches, but reaches in some places 30 inches. It is a true coal, as it rests on a bed of fire-clay full of *Stigmaria*, and is surmounted by shale and ironstone with plants and shells (*Anthracosia*). It yields about 70 per cent. of volatile matter, and is in high request for the

manufacture of gas and paraffin oil.* There are several seams of "brown cannel" in Fifeshire and Edinburghshire, all valuable for gas.

My colleague, Mr. Geikie,† gives the following as the vertical section of the strata in the Mid-Lothian coal-field.

Upper Carboniferous Series.	1. Flat Coal Group. (above 1,000 feet.)	Sandstones, shales, and fire-clays, with seams of coal, occupying the central area of the coal-field.
	2. Roslyn Sandstone Group. (1,500 feet.)	A great series of sandstones and shales, with 3 bands of marine limestone, with *Encrinites*, *Spirifer*, *Producta*, *Cyathophylla*. Two thin coal-seams.
	3. Edge Coal Group. (800—900 feet.)	Sandstones and shales, with many beds of coal, some of which are thick and valuable.
Middle Series.	Roman Camp Limestones. (150—200 feet.)	Marine limestones intercalated with sandstones and shales. A few thin seams of coal, with numerous fossils, *Producta*, *Spirifer*, *Cyathophyllum* more rarely; *Bellerophon* and *Orthoceras*.
Lower Carboniferous Series.	1. Burdiehouse Limestone Group. (27 feet.)	Compact, splintery, and often laminated limestone, crowded with estuarine fossils and plants. Fish: *Palæoniscus*, *Megalichthys*, *Gyracanthus formosus*. Crustacea: *Cyprides* in vast numbers, forming whole beds. Plants: ferns, *Sigillaria*, seed-cones, &c.:
	2. Lower Group; reddish sandstones, shales, and limestones of great thickness.	Lowest beds, unfossiliferous.

* "Ure's Dictionary of Arts, &c.," by R. Hunt, pp. 361-3.

† "The Story of a Boulder." Edinburgh, 1858. A little work full of graphic delineations of Scottish Geology, and, like Hugh Miller's "Old Red Sandstone," clothing scientific truth in a poetic garb.

Mr. Geikie describes in detail the structure and organic productions of the celebrated Burdiehouse limestone, and arrives at the conclusion that it was slowly elaborated at the bottom of an estuary of a river into which the remains of terrestrial plants were drifted from the land, while bone-covered fishes haunted the waters, and huge sharks (the ganoid fishes) ascended from the sea to share in the decaying putrescent matter ever brought down from the interior.*

There are several seams of brown cannel in Fifeshire and in Edinburghshire, all valuable for gas.

Lanarkshire.

The general succession of the coal-seams in Lanarkshire is illustrated by Mr. Ralph Moore's vertical section, of which the following is a synopsis.

The total thickness of beds is 750 fathoms down to the Hurlet Coal, and may be thus divided:—

Upper Series.—From the "Upper Four-foot Coal" downwards, with 840 feet. ten coal-seams from two feet and upwards, and with the "Palace Craig," the "Airdrie," and "Slaty" black-band ironstones.

Middle Series.—From the "Moorstone Rock," which may possibly 960 feet. represent the "Millstone Grit" of England, down to the Garnkirk Limestone.

Lower Series.—Representing the Carboniferous Limestone of England, 2,200 feet. containing six courses of limestone from the Garnkirk band to that which overlies the Hurlet Coal; and several coals, including the *Lesmahagow Gas Coal* and the *Hurlet Coal*, six feet thick—and three courses of black-band ironstone.

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* "The Story of a Boulder," p. 192.

The strata below the Hurlet Coal are not represented in Mr. Moore's section.

Mr. J. Craig, upon the conclusion of an elaborate survey of that portion of the Scottish coal-field from the valley of the Clyde to that of the Leven, has classed the coal series into five groups,* as follows:—

General Section in Lanarkshire and Stirlingshire.

1. *Upper Red Sandstone Series.*—Red sandstones and shales with thin beds of coal.
2. *Upper "Fresh-water" Series.*—With 30 coals, seven or eight of which are workable, with several species of *Anthracosia* (Unio) and fishes, as *Megalichthys Hibberti, Gyracanthus formosus, Ctenacanthus.* Three black-band ironstones.
3. *Upper Marine, or Limestone Series.*—Three or four beds of limestone with shales, and three very thin coals. The limestones contain *Encrinites, Nucula, Bellerophon, Euomphalus, Orthoceras,* &c. Thickness of the series about 200 yards.
4. *Lower Coal Series.*—No limestones, but several coal-seams, the lowest being cannel, with the Keppoch black-band ironstone. Below these, shales with ironstone and limestone bands.
5. *Lower Marine Series.*—Marine limestone resting on alum shale. *Sulphur* coal 6 feet, below which occur a series of lower limestone-shales and sandstones, resting upon Old Red Sandstone, and forming the base of the Carboniferous series.

The whole series here represented exceeds 1000 yards in thickness.

Resources.

We are not at present in a position to give anything like an approximately correct estimate of the area and resources of the Scottish coal-fields: we must wait till the geological surveyors put us in possession of reliable maps and sections. The want of such documents is felt with all its force when we find that with an area of

* Brit. Assoc. Report, 1840.

about 1720 square miles the quantity of coal has been calculated at 153,916 millions of tons by one authority, and at 230,874 by another. From the smaller of these estimates very large deductions would, I feel confident, be necessary, in order to arrive at the supply available for future use.

The quantity of coal raised in Scotland in 1858 was 8,926,249 tons.

CHAPTER XXI.

BRORA COAL-FIELD, SUTHERLANDSHIRE.

A SMALL coal-field occurs at Brora, near the shores of the Dornoch Firth. It is of the age of the Lower Oolite, and perhaps contemporaneous with the carbonaceous strata of Whitby in Yorkshire. It affords the thickest stratum of pure vegetable matter hitherto detected in any Secondary formation in England. One seam of coal of 3½ feet in thickness has been worked extensively for upwards of a century.*

CHAPTER XXII.

IRELAND.

THAT Ireland was once covered over two-thirds of its extent by coal-beds is a proposition which we may confidently affirm on geological grounds; but the misfortunes of the sister isle began long before the landing of

* Lyell, Elem. Geol., p. 315.

Strongbow, for old father Neptune has swept the coal and coal strata clean into his lap, and left little but a bare floor of limestone behind. In plain words, if we examine a geological map of Ireland we shall find that the Carboniferous Limestone overspreads its greater part; and as we always find in England that this formation is ultimately surmounted by Coal-measures, so we may infer there was the same order of succession here, before the sea—which more than once overwhelmed the country after the Carboniferous epoch—remorselessly swept away the most valuable portion of this system of rocks, with the exception of a few isolated tracts now about to be described.

Mr. Jukes, who, with his staff of geological surveyors, is engaged in working out the geology of Ireland, gives the following as the succession of the Carboniferous rocks:*

Coal-fields of Kerry, Cork, and Waterford.

2. Coal-measures.—Shales and cleaved slates, fine-grained grits, with thin coal-seams, more than	2,000 ft.
1. Carboniferous Limestone	1,500 „
Old Red Sandstone.	

The Coal-measures are generally highly inclined, contorted, or inverted, and the beds of coal have been so compressed as to be only a few inches in thickness for many yards, and then suddenly expand into large pockets of coal of a thickness of 20 or 30 feet. Coal-mining is here conducted like vein-mining, and the Coal-measures are of the age of the Upper Limestone Shale of England.

* "Manual of Geology," p. 445. Mem. Geol. Survey of Ireland.

Clare, Limerick, Tipperary, and Kilkenny.

5. Coal-measures.—Similar to those in Cork, but generally lying nearly horizontal. The coals retain their original thicknesses, varying from 6 inches to 3 feet. Coal-plants are abundant, and shells, which in England belong to the period of the Millstone Grit or Gannister beds, as *Goniatites, Bellerophon, Pecten-papyraceus.*
4. Upper Limestone.—Crystalline and compact limestone.
3. Calp or Middle Limestone.—Black limestones and shales.
2. Lower Limestone.—Thick-bedded grey limestone, sometimes crystalline, and often dolomitic and oolitic.
1. Lower Limestone shale.

North of Ireland.—Tyrone, Ballycastle, &c.

In this part of Ireland the Coal-measures appear to belong to the age of those of England, and are underlaid by Millstone Grit. The inferior beds are similar to those above described.

From the survey of Sir R. Griffith, it would appear that the Tyrone coal-field is rich in minerals, though of limited extent. Along the banks of the river Torrent seven workable beds of coal appear, having a combined thickness of 30 feet, and included within 280 yards of strata, which are ultimately covered over by Red Sandstones and Marls, probably of Triassic age.*

The coal of the greater part of the Irish Coal-measures is anthracite, as the well-known Kilkenny coal. The produce of all the coal-fields for 1858 was as follows:—

Anthracite	..	..	80,420 tons.
Bituminous Coal	..	..	40,210 „
Total	..	..	120,630 „

* Geological and Mining Surveys of Tyrone and Antrim: Dublin, 1829. (See Appendix).

PART III.

CHAPTER I.

COAL-FIELDS OF OTHER PARTS OF THE WORLD.

EUROPE.

France and Belgium.—The coal-strata belong probably to two periods, that of the Carboniferous Limestone and of the true Coal-measures. They extend along an axis of elevation from Boulogne to Liege, and are covered throughout the greater part of their course by horizontal strata of the Cretaceous and Tertiary periods, through which they are worked. In Belgium, near Mons, the coal-strata are contorted to such an extent as to assume a vertically zigzag arrangement, so that a vertical shaft passes through the same bed of coal several times.* The united extent of these coal-fields is not less than 1500 square miles.

Rhenish Provinces.—There are coal-fields of at least two periods. The Carboniferous, to which the Saarbrück coal-field belongs, has an area of about 960 square miles. It is remarkable for having yielded the remains of several species of reptiles, named by Professor Gold-

* Lyell, Elem. Geol., 5th Edit., p. 53.

fuss *Archegosaurus*, having characters intermediate between the Batrachians and Saurians.*

The "Brown-coal" formation of the Lower Rhine is considered by Von Buch to be of Miocene age. It yields a lignite of little value, and the associated shales are used in the manutacture of alum.

There are smaller coal-fields in Westphalia, Bohemia, Saxony, Asturias in Spain, and in parts of Switzerland, with a combined area of about 4000 square miles.

In Poland the coal-formation is both extensive and richly stored with mineral fuel.

Russia.—The coal-fields of Russia are considered by Sir R. I. Murchison to belong to the Lower Carboniferous period.† The Carboniferous strata extend in a narrow band along the western base of the Ural range from the Arctic Sea to lat. 51° N. Here they are overspread by the Permian formation, but reappear rising from below the newer rocks of Central Russia, in the government of Riazan and Moscow, and stretch northwards to the White Sea, a distance of 900 miles. This tract is not very productive. The most valuable coal-field is that of the Donetz, which lies to the north of the Sea of Azof. It has an oval shape, the major diameter lying east and west, and about 230 miles in length. Entire superficial area 11,000 square miles. The roofs of the coal-seams, like those of Scotland, are formed of fossiliferous limestone or black shale, with *Producta*, *Orthis* and other marine shells.‡

* *Ibid.*, p. 400. † "Russia and the Ural Mountains," vol. i., p. 69.
‡ *Ibid.*, chap. vi.

CHAPTER II.

INDIA.

THE areas and resources of the coal-fields of India are as yet imperfectly known, but are now undergoing the investigation of the Government geological surveyors, who have already produced some valuable maps and memoirs. The Messrs. Blanford, in their "Report on the Talcheer Coal-Field," have shown that there at one time existed a widely-extended tract of carbonaceous deposits, which have been subsequently dissevered by denudation into the coal-fields of Rampur and Upper Damoodah, and, still further to the east, that of Burdwan.*

In the north-west are the coal-fields of Palamow, Sirgooja, and probably a chain of small fields connecting these with a great carbonaceous district stated to exist north-west of Sumbulpur.

The so-called "Talcheer coal-field" has been shown by Messrs. Blanford to be entirely destitute of coal.† The sedimentary rocks of this coal-field are composed of three groups, each resting unconformably on that beneath it. The middle or Damoodah group is at least of not more recent age than the Permian, as it is overlaid by shales which have yielded a minute Estheria, and the

* This coal-field has been also described by the Rev. Messrs. Hislop and Hunter, English Missionaries. Journ. Geol. Soc., vol. xi.

† Memoirs of the Geol. Survey of India, vol. i, part 1.

cranium of a Labyrinthodontoid batrachian. This coal-field yields rich iron-ores, capable of producing highly tenacious iron.

Professor Oldham describes a small coal-field of Eocene Tertiary age, resting on Nummulitic limestone, in the Khasi hills, Eastern Bengal; and in the north-western part of the same presidency there are extensive tracts yielding coal and lignite.* Of these, the coal formation of Cutch is the best known. It is of the Lower Oolitic period, and is overlaid by sandstone of the age of the Kelloway rock, containing *Ammonites Herveyi*. It would thus appear to be the Indian representative in time of the Brora coal-strata of Sutherlandshire, of the Oolitic coal of Yorkshire, and of Virginia in the United States. —(Lyell.)

As far as our knowledge extends it would appear that the coal-fields of our Indian empire are not highly productive, that the coal is frequently of an inferior quality, and that it has been formed at several periods, from the Carboniferous to the Tertiary inclusive. The extent of the coal-bearing strata is, however, very large.

There are coal-fields in China, first mentioned by Marco Polo; in Borneo, producing, it is said, coal of excellent quality; and in Japan, where coal is stated by Kempfer to occur in large quantities in the northern provinces.

The state of Victoria in Australia contains carbonaceous deposits, from which coal has already been extracted. The Government geologist, Mr. Selwyn, has

* Mem. Geol. Survey, India, vol. i. part 2

been engaged for several years in developing the mineral resources of this highly-favoured colony. Mr. Selwyn states that if the mass of the coal-bearing strata of Victoria be Oolitic (Jurassic), there are certainly others in the eastern districts of the colony which contain plants of the true *Carboniferous* type, while the beds themselves rest and pass downwards into calcareous rocks with fossils, which are nearly all Carboniferous or Devonian forms.* How remarkable, that both here and at our Antipodes, in Britain in the Northern, and Australia in the Southern hemisphere,—countries now standing in the relation of parent and child,—Nature should have been elaborating mineral fuel during the same eventful period of the Earth's bygone history!

New Zealand.—This beautiful island is rich in coal and lignite, which will prove of great value for steam navigation. Mr. C. Forbes describes carbonaceous strata in Preservation Island, Massacre Bay, and Waikato. They all belong to the Tertiary period.†

* "Geology of Victoria," Journ. Geol. Soc., London, vol. xvi., p. 145.
† Journ. Geol. Soc., vol. ii.

CHAPTER III.

NORTH AMERICA.

British Possessions.

THE United States have retained possession of by far the greater portion of the coal-producing region of America. In Canada, there is not a trace of the Carboniferous formation; and the coal-fields within the boundaries of the British Empire, are confined to its outlying north-eastern districts, lying south of the River St. Lawrence. They are as follows:—

1. Newfoundland.*—A small field, with sandstone, variegated marls, gypsum, and coal, St. George's Bay. Area supposed to be about 100 square miles.
2. Cape Breton.†—Area 200 square miles. This district is interesting for the fine example it affords of erect stems of fossil-trees, giving evidence of at least fifty-nine forests buried in succession. Some of the beds show casts of rain-prints, worm-tracks, sun-cracks, and ripple-marks.
3. Pictou.—Area 350 square miles.‡
4. Cumberland.—Area 200 square miles.§
5. New Brunswick.—Area 6,689 square miles, only a small part of which is productive.‖

The coal-field of Nova Scotia includes the districts of Pictou, Cumberland, and Cape Breton. It contains a

* Jukes' "Geology of Newfoundland."
† Mr. Richard Brown, Journ. Geol. Soc., vols. ii. and vi.
‡ Professor Rogers, "Geol. of Pensylvania," vol. ii. p. 101.
§ *Ibid.* ‖ *Ibid.*

total thickness of strata of no less than 14,570 feet,* with 76 seams of coal. Along the coast of the Bay of Fundy, at South Joggins, is laid open one of the finest natural sections in the world. The strata rise along the face of the cliff, which is 150 feet high and upwards, at an angle of 24°, and a vertical thickness of 4515 feet is brought to light. Sir C. Lyell counted 19 seams of coal, and at least 10 forests of upright stems of *Sigillaria*, of which the longest was 25 feet, and when broken off, four feet in diameter, and they were found almost invariably based on the upper surfaces of the beds of coal. The fossil shells resemble those of the Middle Coal-measures of England, consisting of *Anthracosia* (Unio), *Modiola*, *Spirorbis*, and *Cypris*.† Of fish: *Holoptychius* and *Palæoniscus*. Of reptiles: *Dendrerpeton*, a batrachian, allied to those now inhabiting the North American rivers, discovered by Sir C. Lyell and Dr. Dawson in the interior of an erect trunk of *Sigillaria;* and along with it the first example ever found of a *land shell*, probably a *Pupa*.

Very recently Dr. Dawson has discovered, within the upright trunk of a Sigillaria, numerous specimens of the same shell, which he has described and figured under the name *Pupa vetusta*, together with remains of reptiles of the genus *Dendrerpeton*, and a body which he considers to be that of a worm or myriapod.‡

* According to the estimate of Sir W. Logan.

† Lyell. Elem. Geol., 5th edit. p. 379.—See also Mr. J. W. Dawson's Memoirs in the Journ. Geol. Soc., London.

‡ Journ. Geol. Soc., vol. xvi.

CHAPTER IV.

UNITED STATES.

The great hydrographical basin of the Mississippi and its tributaries, is underlaid throughout the greater part of its area by productive Coal-measures, with enough coal to supply the whole of that vast continent, were it as populous and as industrious as Britain, for a decade of centuries. This great Carboniferous formation spread originally in one continuous sheet over the whole of Central America, probably from the flanks of the Rocky Mountains to the shores of the North Atlantic, and from the Gulf of Mexico to Newfoundland; and though we are unable strictly to define the original margin and limits of this great coal-generating tract, yet there is reason to believe, as has been pointed out by Sir C. Lyell, that land existed at that period where now rolls the Atlantic, and that the British Islands were connected with America by a chain of islands, or a tract of land, over which the plants of the Carboniferous period migrated and spread themselves in dense forests. Such an hypothesis seems the most satisfactory explanation for the remarkable fact, that the Carboniferous vegetation of America is identical, at least generically, with that of Europe; which could not have been the case under any of the received theories of the distribution of plants

and animals, if these regions had been separated by wide barriers of ocean.

Moreover in tracing the Carboniferous strata, from Texas and Missouri on the south-west to the Alleghany Mountains and Nova Scotia on the east and north, we find a constant thickening of the sedimentary materials, such as sandstones and shales, which become both more abundant, and of coarser texture, as we approach the sea-board of the eastern states. This points to the position of the old land, from which these materials were derived, as having lain somewhere in the North Atlantic; and combined with the evidence derived from the vegetation, becomes almost demonstrative of the axiom, that what was land is now sea.

The great tract of Coal-measures, which was, without doubt, originally connected throughout, has now become dissevered into five coal-fields, the areas of which are thus stated by Professor Rogers:—*

The Appalachian Basin.—Length, 875 miles; average breadth, 180; area	55,500 sq. miles.
The Illinois, Indiana, and Kentucky Basins.—Length, 370; breadth, 200; area	51,100 ,, ,,
The Missouri and Arkansas Basins.—Length, 550; breadth, 200; area	73,913 ,, ,,
The Michigan Basin.—Length, 160; breadth, 125; area	13,350 ,, ,,
The Texas Basin.—Length, 160; area ..	3,000 ,, ,,
Total area	196,863 ,, ,,

* "Geol. of Pennsylvania." The reader would do well to refer to the small but very beautiful map of M. Jules Marcou, in Peterman's "Mittheilungen," vol. vi., 1855.

Over the central and western districts, the strata lie regularly, and only slightly removed from the horizontal position; but on proceeding eastwards, and approaching the chain of the Alleghanies, they become bent; and ultimately folded and crumpled along lines parallel to the axis of the mountains. Corresponding with this folding of the beds, the coals lose their bituminous properties, and along the western flanks of the mountains occur only as anthracite. The close connection between the crumpling of the coal-seams, and the loss of the volatile constituents of the coal itself, is strongly marked; for in proportion as we recede from the axis of disturbance, the coal-seams become more bituminous.

The Alleghany Hills consist of a succession of parallel ridges, divided by narrow and deep valleys, corresponding to the folding of the strata. The axis is nearly parallel with the coast of the Atlantic, and reaches at Black Mountain an elevation of 6476 feet. The geological structure of this remarkable range leads to the conclusion, that it has been formed by the exertion of lateral pressure, acting along the Atlantic side, and forcing the strata towards the west, with a power to which geology affords few parallels. In consequence of the structure of the beds, and the subsequent partial denudation, these mountains contain several small trough-shaped coal-fields, in which the coal has become metamorphosed, and assumes a columnar structure, the axes of the columns being perpendicular to the planes of bedding. There are also springs of pitch and petroleum, of great value; and others of brine, containing 10 per

cent. of common salt (chloride of sodium), and small quantities of iodine and bromine. Free carburetted hydrogen also bursts forth at the fountains of the country.*

The thickness of some of the coal-seams is in keeping with the vastness of the coal-fields. In consequence of the thinning away of the sedimentary materials westward, several seams are often brought into contact, and form one mass. In the Bear Mountains there has thus been formed a seam of 40 feet in thickness, which is described by Sir C. Lyell. It is anthracite, and is quarried from the outcrop into the hill. Sir Charles considers that the thickness of the original mass of vegetable matter, before condensation by pressure, and the discharge of its various gases, may have been from 200 to 300 feet!

The Coal-measures, as in England, rest upon a floor of Carboniferous Limestone, with, in some places, Millstone Grit intervening; the age of the coal-fields in both countries is therefore identical. The fossils of the Carboniferous Limestone are generically the same with those of Europe—such as *Spirifer*, *Orthis*, *Terebratula*, *Producta*, *Pentremites*, and *Retepora*.

The plants from the Coal-measures are *Lepidodendron elegans*, *Sigillaria Sillimani*, *Neuropteris cordata*. *N. Loshii*, *Pecopteris lonchitica*, *Calamites Cistii*, &c., of which all but the second occur in Europe.

* Professor Rogers. From a communication to the British Association, 1860.

The Jurassic Coal-field of Richmond, Virginia.

Some miles east of Richmond a small coal-field of 26 miles from north to south, and 12 in its greatest diameter, occupies a depression in the granitic rocks of that part of the country. This coal-field has been shown by Professor Rogers and Sir C. Lyell to be of an age contemporaneous with the Oolitic coal-field of Whitby in Yorkshire, and the plants *Equisetum columnare* and *Pecopteris Whitbyensis* are abundant in both places.

The Richmond coal-field contains several beds of valuable coal, one of which is from 30 to 40 feet in thickness, highly bituminous, and equal to the best coal of Newcastle.

Other Coal-fields and Lignite Formations.

Coal-fields of smaller extent and uncertain age occur, according to M. Marcou, at the sources of the Rio Colorado, in the Utah territory, and on the shores of the Pacific Ocean north of Cape Blanco.*

In Vancouver Island, and on the opposite coast of America, there are extensive deposits of Tertiary age, bearing thick beds of lignite, which are extensively worked for the supply of the steamers navigating between Victoria and the Frazer River.†

* "Geologische Karte der Vereingten Staaten," in Peterman's "Mittheilungen," 1855.

† Mr. Bauerman, "Journ. Geol. Soc.," vol. xvi., p. 201.

Mr. Isbister describes extensive lignite deposits in the valley of the Mackenzie River, probably of the same geological age as those in Vancouver Island. These strata have been traced by Sir J. Richardson from the shores of the Arctic Sea, along the eastern base of the Rocky Mountains as far south as lat. 52°. The beds of lignite attain a thickness of 9 feet, and are well shown where the Bear Island River flows into the Mackenzie.

Coal and lignite occur on Jameson Land, Banks' Land, and Melville Island; and in Albert Land, in lat. 78°, Sir E. Belcher found bituminous schists with coal, and apparently connected with these strata, limestones with *Producta* and *Spirifer*. We have, therefore, grounds for believing, from these monuments of the Carboniferous age, that our coal-vegetation extended into regions which are at present so inhospitable as almost to exclude the existence of vegetable life. How great and wide-spread the changes of climate, and how mysterious the cause!

Produce of the American Coal-fields.

The annual quantity of coal raised in the United States is about five millions of tons.* If to this we add one million for the produce of the coal-fields in the British possessions, we have a total for the whole of America of six millions of tons.

Now, taking the area of these coal-fields at 204,000

* Taylor's "Statistics of Coal," 2nd edit., Philadelphia.

niles, and comparing it with that of the English
ds, 2779 square miles, we find that the former is
s larger than the latter, but the quantity of coal
a America is only 1-10th the amount raised in
l and Wales. In other words, if the coal-fields
rica were developed to as great an extent as those
land, they ought to raise 452 millions of tons
y, or 72 times more than at present.

PART IV.

AN INQUIRY INTO THE PHYSICAL LIMIT TO DEEP COAL-MINING.

THE reader will have observed that I have confined my calculations of the resources of our coal-fields to that portion of them included within 4000 feet of the surface, notwithstanding there are hundreds of miles stored with coal at greater depths than this. It is therefore proper that I should explain the grounds on which I consider, not only that all the coal below 4000 feet must for ever remain beyond our reach, but that, in confining myself to this limit, I have even exceeded to some extent the available limit of depth.

There are two agencies in mining constantly acting with increasing energy as we descend vertically from the surface—temperature and pressure; and though at first sight the latter would appear likely to offer the greatest obstacles to deep mining, it will probably be found that in reality increase of temperature will prove the first insuperable barrier. Let us examine this subject further.

The phenomena of volcanos, hot springs, and igneous corks, all tend to the conclusion of the internal fluidity

of the earth at great depths, owing to increase of temperature; but it is to direct experiment that we are indebted for a knowledge of the extent to which this internal heat affects the upper crust of the earth. The following are some of these experiments as recorded by Arago.*

At Paris, an artesian well, the Puits de Grenelle, passes downwards through the Chalk to a depth of 500 metres, and though in some parts the temperature increases more slowly than in others, the general result was found to be an increase of 1° Fahr. for every 60 feet.

At Saltzwerk, in Westphalia, a similar boring was carried to a depth of 644½ metres, and the result was an increase of 1° F. for every 54 feet.

Near Geneva an artesian boring gave an increase of 1° F. for every 55 feet.

At Mondorff, in the Grand Duchy of Luxemburg, an artesian boring, of great interest from the number of formations which were penetrated, gave the result of 1° F. for every 57 feet. The details were as follows:—

	Metres.
Lias	54·11
Keuper	206·02
Muschelkalk	142·17
Grès bigarré	311·46
Old Schistoze Rocks ..	16·24
	730·00

* See also Mr. W. Hopkins' Essay in the Philosophical Transactions, vol. 147, part 3. This eminent authority considers the increase of temperature of about 1° F. for every 60 feet, as having been proved without controversy.

The writer of the article, "Mines and Mining," in the Encyclopedia Britannica, states that in many of the deep mines of Cornwall the temperature exceeds 90° F. In the Tresavean mine, which is about 2112 feet below the surface, the temperature ranges between 90° and 100° F., and some of the water from the deep levels of the United mines stands at 106° to 108° F. These results would give an increase of 1° for every 56½ feet.

Professor Phillips has made observations on the temperature at the Monkwearmouth colliery, which has shown an increase of about 1° for every 60 feet.

The experiments lately carried out by Mr. Astley, during the progress of sinking the Dukinfield colliery, are perhaps the most valuable of any hitherto undertaken in this country. Through the kindness of Mr. Fairbairn of Manchester, I have been supplied with the whole of the details, which I here insert at length. The observations were conducted with great care. The thermometer was inserted in a dry bore-hole, and removed as far as possible from the influence of the air in the shaft, and left in its bed for a length of time, varying from half an hour to two hours. The results also carry with them more than usual importance, from the fact that they extend downwards to a depth of 2055 feet, with an additional observation made in the open workings, at 120 yards from the shaft, and at a depth of 2151 feet.*

* Mr. Fairbairn has kindly allowed me to make use of these experiments for publication, but they will probably soon appear from himself in a more extended form.

Thermometrical Observations in the Dukinfield Colliery, Cheshire, between 1848 *aud* 1859.

Date.	Depth in Yards.	Temperature Fahr.	Description of Stratum.
1848. July 28th ..	5·6	51°	Red rock—no variation.
1849.			
1st ..	231	57·7	Blue metal—wet
12th	234·7	58	ditto dry hole
16th	237	58	ditto ditto
July 14th	239	57·5	
" 16th	240	58	ditto ditto
" 27th	242	57·5	ditto ditto
August 9th	244	58	ditto ditto
" 25th	248	58	ditto water
" 27th	248	57·25	ditto ditto
" 31st	250	57·25	ditto ditto
November 14th	252	58	
December 6th	256·5	58	Blue shale—dry
" 15th	262·5	58·5	ditto do.
" 22nd	270	58	Bituminous shale—dry
1850.			
January 9th	279	58·5	Strong warrant earth
" 26th	286·5	59·12	Rock bands
February 11th	293	59·5	Coal roof
" 19th	300	59·87	Warrant earth
March 5th	309	59·87	Purple mottled shale
1851.			
June 9th	358	62·5	Warrant earth
August 14th	373	64	Tender blue shale
November 7th	403	65	Coal roof
" 19th	419	65·37	Rock bands
1852.			
February 6th	433	66·5	Black shale
May 28th	446	67	Strong fire-clay
1857.			
February 28th	483·5	67·25	Sandstone—dry hole
March 7th	487	67·76	Shale
April 11th	501	68·5	Sandstone
May 6th	511·5	68·75	Blue shale
" 19th	521·5	69·38	Strong shale
June 9th	533	69·75	Warrant earth
" 22nd	539	69·88	Blue shale
" 27th	546	71·75	Coal and earth
July 18th	555	71·25	Grey rock

Thermometrical Observations, &c.—continued.

Date. 1857.	Depth in yards.	Temperature Fahr.	Description of Stratum.
August 1st	563	72·25	Red rock
„ 15th	569	71·25	ditto wet hole
September 2nd	578	72·12	ditto ditto
„ 19th	589	71·5	ditto ditto
October 3rd	597	72·25	Grey rock—dry hole
„ 17th	608	72·25	Coal roof—wet hole
„ 27th	613·5	72·25	Coal floor ditto
1858.			
March 22nd.	621	72	Strong shale—dry
„ 29th	627	71·5	Dark-blue shale
April 23rd	645·5	72·25	Shale—dry hole
May 1st	651	72·25	ditto ditto
„ 19th	658	72·5	ditto ditto
June 9th	669	73·25	Bituminous shale—dry hole
„ 19th	673	74·12	Grey rock
July 17th	683	75·25	Blue shale
„ 21st	685	75·5	do. do.
1859.			
March 5th*	717	75·0	"Black Mine" Coal roof.

Note.—The irregularities observable in the table are always to be expected in such cases. They arise from several causes, such as difference of density, conducting power, and moisture in the strata. Sometimes the water percolated to the bulb, and slightly affected the results.

1. The first observation gives 51° as the invariable temperature throughout the year at a depth of 17 feet. Between 231 yards and 270 yards, the temperature was nearly uniform at 58·0. And the increase from the surface would be at the rate of 1° F. for 88 feet.

2. Between 270 and 309 yards, the increase was at the rate of 1° for 62·4 feet.

3. Between 309 and 419 yards, the increase was at the rate of 1° for 60 feet.

4. Between 419 and 613 yards, the increase was at the rate of 1° for 86·91 feet.

* In workings at 120 yards down engine incline from the shaft.

5. Between 613 and 685 yards, the increase was at the rate of 1° for 65·6 feet.

6. The last observation, taken in the mine itself, at 120 yards from the pit, is valuable, as showing that the temperature of the air does not greatly differ from that of the surrounding strata.

The result of the whole series of observations gives an increase of 1° for every 83·2 feet, which is a less rapid increase than that exhibited by the generality of experiments.

It is not easy to account for the less rapid increase of temperature, as shown by these experiments, than that determined by a large number from other sources. It may possibly happen that the Coal-formation, formed as it is of a great variety of strata differing in density and conducting power, may present greater obstacles to the upward extension of subterranean heat than formations of more uniform texture. But whatever may be the cause, the above results justify us in assuming a more gradual increase than 1 degree for 60 feet, in the case of coal-mines; and if we adopt an amount of 1 degree for 70 feet, which is a mean value between the results obtained at Dukinfield colliery and other sources, we shall not greatly err.

In endeavouring, then, to ascertain what would be the temperature in coal-mines at a greater depth than 2000 feet, we must first determine the temperature to which the addition of 1 degree for 70 feet is to be made. This is shown by the first observation recorded in the above table—viz., 51 degrees, at 17 or 18 feet. In general it has been found that at a certain depth,

varying from 15 to 50 feet, the temperature remains the same all the year round; and is nearly that of the mean annual temperature of the air. At Greenwich, the mean temperature is 49·5°; and in the deepest of several under-ground thermometers, 25 feet from the surface, the extreme variations were (1858), from 48·85° to 52·27°, giving a mean of 50·56°*—a result, differing by only half a degree from that of Dukinfield colliery, obtained ten years earlier.

We may therefore adopt 50·5° as the standard of departure—or in other words, the temperature of no variation at a depth of 50 feet underground.

But there is an additional element tending to increase the heat in deep mines; namely, the increased density of the air. This is a constantly augmenting quantity, but may be taken, for general purposes, at 1 degree for every 300 feet of depth.

Combining these two elements, we obtain the maximum temperature at the various depths shown in the following table:—

Table showing the theoretical increase of Temperature at several depths; the "temperature of no variation" being taken at 50·5° *Fahr., at a depth of* 50 *feet from the surface.*

Depth in feet.	Increase of Temperature due to depth.	Increase of Temperature due to density of air.	Resulting Temperature.
1,500	21·42	5·0	76·92
2,000	27·85	6·5	84·85
2,500	35·5	8·5	94·00
3,000	42·14	9·83	102·47
3,500	49·28	11·66	111·44
4,000	56·42	13·16	120·08

* "Greenwich Observations" for 1858.

The above results give a more rapid increase than that offered by direct experiment at Dukinfield colliery; but, as I have already observed, the results there obtained appear to be exceptional.

From the above calculation it is evident that, were there no compensating agencies, a depth of about 2500 feet would be the limit to deep mining; as it would not be possible for our miners to work at a higher temperature than 94°, almost that of the tropics.

Ventilation is the great means to which we must look, not only for supplying pure air, but for keeping the mines sufficiently cool for mining purposes. It is not improbable that the constant flow of cooler air through the arteries of a mine, will have the result of ultimately lowering the temperature of the strata through which it passes. Its effect must be to carry away a supply of caloric given off from the heated surface of the rock, and thus eventually to reduce the temperature of the mine. We all know how much hotter are the narrow, ill-ventilated parts of a mine, where a thorough draft has not yet been established, than the main passages through which the air constantly circulates. On this point, the experiments which have been kindly undertaken by my friend Mr. C. Wright, at Shireoak colliery, tend to throw some light. Premising that this colliery has been but recently opened, and that the workings are not at present very extensive, it was found, first, that the "intake air"* had a temperature of 63°; while the

* *i. e.* The air at the bottom of the shaft, before entering the passages.

"return air" was 69°, or 6° higher,—certainly a moderate increase of temperature; but, be it remembered, after a comparatively short circulation.

In a "goaf" or chamber, removed seven yards from the air-current, the temperature was 72°; being an increase of 9° upon the "intake air."

Lastly, in a "close heading," 80 yards from the air-current, the temperature was found to be 86°, or no less than 23° higher than that of the intake air. It is not improbable that in this heading a certain amount of heat was generated by spontaneous combustion.

These results show the effect of a free current of air through the works in moderating the heat due to the causes above assigned.

The depth of Shireoak colliery is 510 yards, or 1530 feet. Now, according to the calculation given in the above table, the temperature ought to be 77·45 degrees, which is about a mean between that in the "goaf," seven yards from the air-current, and that in the "close heading," 80 yards from it. Again the temperature of the "return air," which had passed through the workings, was 69°, or nearly 10° under that due to the depth. We may therefore conclude that the *general* effect of the ventilation would be to reduce the temperature by about 10°.

We must also take into consideration the effect of the ventilation at different seasons of the year. This is considerable. I have known water, at the bottom of a deep pit, to have been frozen several inches during the prevalence of severe frosts. Therefore, if the current-air should descend the shaft, and enter the works at a

temperature of from 30° to 40°, there is every probability that it would be able to reduce the heat even of a mine 4000 feet in depth, to a degree not only tolerable, but admitting of healthy labour.

I therefore look forward to the possibility of mines being carried down to such a depth, that it will be practicable to excavate the coal during the winter months only.

Pressure.—It is impossible to speak with certainty of the effect of the accumulative weight of 3000, or 4000 feet of strata on mining operations. In all probability, one effect would be to increase the density of the coal itself, and of its accompanying strata, and so to increase the difficulty of excavating. Coal-mining labours under a disadvantage not felt in mining other minerals, namely, the impossibility in general of having recourse to blasting. The increased firmness of the strata will most assuredly be felt; but the question whether its resistance will prove beyond the powers of manual skill and mechanical contrivances to surmount, can only be solved by actual experience.

In the face of these two obstacles—temperature and pressure, ever increasing with the depth—I have considered it utopian to include in calculations having reference to coal-supply, any quantity, however considerable, which lies at a greater depth than 4000 feet. Beyond that depth, I do not believe it will be found practicable to penetrate. Nature rises up and presents insurmountable barriers.

Within that depth everything is possible.

RECAPITULATION.

The results at which we have arrived are briefly as follows:—

1. There are coal-deposits in various parts of England and Wales, at all depths, down to 9000 or 10,000 feet.
2. That mining is possible to a depth of 4000 feet, but beyond this the high temperature will prove a barrier.
3. The temperature of a Coal-mine at a depth of 4000 feet will probably be found as high as 120° Fahr.; but there is reason to believe, that by the agency of an efficient system of ventilation, this temperature may be so reduced, at least during the cooler months of the year, as to allow of mining operations without unusual danger to health.
4. That for working mines of greater depth than 2000 or 2500 feet, underground stages, with independent winding machinery and engines, will be found not only to render very deep mining practicable, but also to lessen the amount of risk from accident.
5. Lastly. Adopting a depth of 4000 feet as the limit to deep mining, there is still a quantity of coal in store in England and Wales, sufficient to afford a supply of 60 millions of tons for about a thousand years.

APPENDIX.

A.

Rose Bridge Colliery, near Wigan.

In this colliery two, or rather three, coal-seams are worked. The shaft was originally sunk to the "Pemberton Four-feet" Coal in 1854, and for three years this seam was worked to a considerable extent. In September, 1857, another shaft was commenced at some distance from the former one, to extend from the "Pemberton Four-feet" mine to the "Cannel" and "King" Coals which here lie nearly close together, and which were won on June 30th, 1858. Engine, boiler, and winding machinery were then erected in a chamber hollowed out in the workings of the Pemberton Four-feet Coal, and the trucks from the workings of the Cannel and King Coal, after having been lifted by the underground engine are wheeled along a tramway to the bottom of the upper shaft, through which they are raised to the surface.

The use of two or more lifts or stages produces a loss of time and outlay, but has the advantage of allowing of the working of very deep coal-beds without the risks and dangers always attending such undertakings. It is probable that this means will be generally adopted for working coal-seams from 2000 to 3000, or even 4000 feet in depth.

B.

Stray Notices of Ancient Coal-works.

Horseley, in his "Britannia Romana," speaking of some inscriptions found at Benwell, near Newcastle-upon-Tyne, the Condercum of the Romans, states that there was a "coalry not far from that place, which is judged by those best skilled in such affairs to have been wrought by the Romans." This passage is quoted by the author of the "History and Description of Fossil Fuel," &c., a work to which I must refer the reader for much valuable information on the manner of working coal, its uses, and a large amount of detail relative to coal-mining.

Wallis, in his "History of Northumberland," states that in digging some of the foundations of the city of Magna or Caervorran, in 1762, cinders, in all respects similar to those derived from coal were found in considerable quantity.

Mr. T. J. Taylor, in an article on the "Archæology of the Coal Trade," in the Proceedings of the Archæological Institute of Newcastle, vol. i. p. 151, also refers to the discovery of coal-cinders as part of the relics of the Roman stations of the neighbourhood, notices of which are contained in the records of the Antiquarian Society of that town.

C.

The passages from the Boldon Book have been differently translated from the manner here adopted; the word "faber" being rendered "smith," and "carbones invenit" "finds his own coal." This translation of the latter passage is certainly incorrect, and I do not see any good reason for adopting a general term for the proper name in the former.

D.

Notices of Coal-mining between the years 1200—1700.

The anonymous author of the "History of Fossil Fuel," observes in reference to the 13th century: "The strongest and most unequivocal proof that this species of fuel (coal) was in use amongst us during the reign of Henry the Third is to be found in an inquisition preserved among the additions to Matthew Paris's History, of the date of 1245. Here we find it called *carbo maris*, or *sea-coal*,—an appellation retained through succeeding centuries,—with express mention of making pits to win it, and of the wages of the colliers that wrought in them."

Leland, in his Itinerary, vol. viii., has the following passage:—The vaynes of the se-coles ly sometyme upon clines of the se, as round about Coquet Island, and other shores; and they, as some will, be properly called se-coles; but they be not so good as the coles that are digged in the inner part of the lande."

We have numerous references to the use of coal in the 14th century. Surtees, in his "History of Durham," mentions a coal-mine in connection with the vicarage of Merrington, in the county of Durham, in 1343; as also the notice of the sinking of pits at Ferryhill, in the same county. (See p. 180.)

Mr. Taylor, in the Memoir already alluded to, says, "We have thus a tolerably clear historical account of the Newcastle coal-mining and its adjuncts in the 14th century. We have seen that collieries were then certainly opened over a considerable extent of our coal-field, since they were being worked in the districts of Newcastle, Elswick, Birtley, Winlaton, Merrington, and Lanchester. To these may be added coal-mines in Bedlingtonshire, the produce of which was probably shipped in the river Blyth (Northumberland), for

we find the Bishop of Durham in 1368 appointing a supervisor of the mines of that district. That coals were also shipped from Sunderland in the same century we have proof in the rolls of Whitby Abbey in 1395, when 13 shillings and 4 pence were paid to William Rede of Sunderland for four chaldrons of coal." Proc. Archæol. Inst. Newcastle, vol. i. p. 160.

The use of coal in London was resumed within a few years after its prohibition by the king in 1306; as we find in the "Petitiones in Parliamento," in 1321-2, a claim made for ten shillings, on account of coal which had been ordered by the clerk of the palace, but the payment for which had been neglected.

Amongst other incidental notices of coal in the 14th century is that of Æneas Sylvius, afterwards Pius II. On his visit to Scotland he had opportunities of witnessing the poor receiving as alms at the gates of the monasteries pieces of coal, "which" he states, "they burn in place of wood, of which their country is destitute." Æneï Sylvii Opera, p. 443. (See p. 179.)

Coal-mines are also mentioned in the abbey leases of this century. Tynemouth priory had a colliery at Elswick in 1330, let at a yearly rental of six marks, to be paid so soon as the tenant commenced working the coal. The rent of another new colliery in 1334 is stipulated at 40*s*. yearly. Proc. Arch. Inst. Newcastle, vol. i. p. 156.

In the reign of Queen Elizabeth the coal-trade flourished greatly, and continued to be regarded as an important source not only of local but of national revenue by succeeding monarchs. In the reign of Charles I. the trade was burdened by excessive taxation and grievous monopolies. After the capture of Newcastle by the Scottish army, the House of Commons undertook the regulation of the coal trade, by

which step abundant supplies were shipped into the port of London for the use of the poor, coals having risen to the price of 4*l.* per chaldron. Hist. Fossil Fuel, p. 316.

In 1699, Newcastle had two-thirds of the coal-trade, and 300,000 chaldrons, in all, went annually to London. The over-sea trade employed 900,000 tons of shipping. Coals about that time sold in London for 18*s.* a chaldron, out of which 5*s.* were paid to the king, 1*s.* 6*d.* to St. Paul's, and 1*s.* 6*d.* metage. It was then stated to the House of Commons that 600 ships, one with another of the burden of eighty Newcastle chaldrons, were employing 4,500 men, requisite for carrying on the trade. *Ibid.* p. 318.

Æneas Sylvius, afterwards Pope Pius II.

The following is the passage taken from that part of the travels of Æneas Sylvius, relating to Scotland. The account of that kingdom is finished off within the space of one page, which, however, is as much as it had any right to expect, the whole of the British Isles being graphically portrayed by means of three times that quantity of letter-press, and of a sketch-map, which is the more easy of comprehension, as it ignores distance, and is remarkable for simplicity of detail. After dwelling on the scarcity of trees for fuel and other purposes in Scotland at this time (probably the end of the 14th century), he proceeds to describe the following marvellous spectacle, of which he was a witness, "Nam pauperes penè nudos ad templa mendicantes, acceptis lapidibus eleemosynæ gratia datis, lætos abiisse conspeximus; id genus lapidis, sive sulphurea, sive alia pingui materia præditum, pro ligno, quo regio nuda est, comburitur."—*De Scotia:* "Opera," chap. xlvi.

"Ordinatio Vicaræ Ecclesiæ de Merrington," 1343.

"Necnon, et medietatem pecuniæ dedecima mineræ carbonem Willielmi de Het, et heredum suorum." "History of Durham," by R. Surtees, 1828. Appendix, vol. iii, p. 396.

E.

Lighting Mines before the invention of the Davy Lamp.

There were, however, other means adopted for giving a feeble and uncertain light. The steel mill was the invention most frequently employed in the northern counties; a description and figure of which is given in the "History of Fossil Fuel." By means of a multiplying wheel, a steel periphery was made to revolve rapidly in contact with a piece of flint, by which a succession of sparks was produced. The sparks, being formed of minute particles of steel heated to redness, are incapable of igniting the explosive gases of the mine, though sufficiently bright to light dimly the workings. In those mines where carburetted hydrogen gas existed in minute quantities, naked candles were employed for lighting, and gunpowder for blasting.

F.

I adopt, without hesitation, these statements of the production for France, Belgium, and Saxony, from a valuable work, published while these pages were passing through the press, "On Coal and Iron, &c.," by Mr. W. Fordyce, of Newcastle-upon-Tyne, the author having derived them from official returns. The quantity is considerably larger than that I had previously supposed, and which I had derived from other sources.

G.

The following explanation of the terms here used, as given by Sir C. Lyell, may be of service to those unfamiliar with botanical nomenclature, especially in its application to palæontology.

	Brongniart.	*Lindley.*	
Cryptogamic.	1 Cryptogamous amphigens, or cellular cryptogamic.	Thallogens.	Lichens, sea-weeds, fungi.
	2 Cryptogamous acrogens.	Acrogens.	Mosses, equisetums, ferns, lycopodiums, — (Lepidodendron, Sigillaria ? calamites, &c.)
Phanerogamic.	3 Dicotyledonous gymnosperms.	Gymnogens.	Conifers and Cycads.
	4 Dicot. Angiosperms.	Exogens.	Compositæ, leguminosæ, umbelliferæ, cruciferæ, rosaceæ, forest trees, &c. Probably no representatives in the Carboniferous flora.
	5 Monocotyledons.	Endogens.	Palms, lilies, aloes, rushes, grasses.

H.

Coal-mining in China.

Marco Polo, who travelled through China towards the close of the 13th century, mentions coal as one of the commodities in use in his time in that country. At the present day, it is worked in the cliffs of the Pe-Kiang river at Ting-tih, by means of adits driven into the side of the hill at the out-crop of the coal-seams. The works are carried on in the most primitive manner, without the aid of machinery; and the mode of working coal through vertical shafts, which may be considered, as the second stage in the act of mining,

appears still unknown. In this respect, as in almost every other, the Chinese are far behind their neighbours the Japanese. Probably, if an inhabitant of the celestial empire were shown some of the largest collieries of Newcastle, or Wigan, he would scarcely deign to look at them, or would gravely inform you that they have similar, or better machinery, and deeper mines "Pekin side."

Mr. Oliphant states that coal is procured from a mine about five miles distant from the important city of Whang-shih-kang, or "Yellow Stone," on the river Yang-tse-kiang, situated about 400 miles from its mouth.—"Narrative of Lord Elgin's Mission to China and Japan," vol. ii. p. 389.

Coal-mining—Japan.

Mr. Oliphant states that coal is raised in Japan somewhat extensively—but as a Government monopoly. One mine, at a place called Wuku Moto, in the interior of the main island of Niphon, was visited by some of the Dutch Mission. They describe the mine as being well and judiciously worked, and the coal as bituminous in its nature, and made into coke for use.

That the coal is worked by means of vertical shafts appears from the fact that the Prince of Fizen once ordered a steam-engine from Europe for pumping the water out of his mines; but, through the native jealousy of the presence of foreigners in the country, refused to allow the Dutch engineer to erect the machinery upon the spot. The Japanese, however, are quite independent of European aid for such an object, as they thoroughly understand the construction and management of the steam-engine.—"Lord Elgin's Mission to China and Japan," vol. ii.

Kempfer, in his "History of Japan," also refers to the abundance of this mineral—stating that it is dug in great

quantity in the province of Tsekusen, and in most of the northern provinces. This rich and productive empire also yields abundance of gold, silver, copper, and iron; and the Japanese armourers excel the Europeans, and perhaps any other nation, in tempering steel.

I.

Mr. Fordyce in his "History of Coal, Coke, and Coal-fields, 1860," gives the following account of the calculations which have been made regarding the duration of the Great Northern Coal-field of Durham and Northumberland. He says: "The most able mining engineers have based their calculations upon the various workable coal-seams, and upon the consumption of coal at the time of their inquiry; hence different results have been arrived at without their being any material difference of opinion as to the quantity of coal yet unworked. Mr. Hugh Taylor, in his evidence before a Select Committee of the House of Lords, in 1829, based his calculations upon the consumption of coal at 3,500,000 tons per annum, and therefore estimated the duration of the Northern Coal-field at 1727 years. This opinion has been adopted by various subsequent writers who, it would appear, have overlooked the annually increasing demand for the coal of the district. Were Mr. Hugh Taylor giving an opinion at the present time, with a consumption of about 17 million tons per annum, instead of 3,500,000, it would only prove his statement to be pretty nearly correct as to the quantity of workable coal in the counties of Durham and Northumberland. Mr. Greenwell states that 'the Northern Coal-field would continue 331 years;' his estimates were made in 1846, at which time he gives the consumption of coal at the rate of upwards of 10 millions of tons per annum. Mr. T. Y. Hall, in

1854, referring to the estimates of Mr. Taylor and Mr. Greenwell, states, 'that various methods of calculations by sections of different districts have been tried both by Mr. Greenwell and myself, unknown to each other, and the results, which it was impossible to anticipate, have been found to be perfectly similar as regards quantity.' Mr. Hall, in 1854, takes the annual consumption of coal at 14 millions of tons, including the small coal as saleable, and gives 365 years as the period at which this coal-field will be exhausted. He estimates the total quantity of coal that may be workable under the area of 750 square miles at . . . 8,182,805,757 tons.

Deducting for loss and waste .	1,608,561,151	„
Ditto for quantity already extracted	898,812,433	„
Ditto for casualties, &c. .	553,543,217	„
Leaving for future use . .	5,121,888,956	„

This quantity divided by 14 millions, annually extracted for sales and pit consumption, gives 365 years. But from the great annual increase in the demand for coal from this portion of the coal-field of Great Britain, Mr. Hall assumes that the consumption is not unlikely, before many years elapse, to reach not less than 20 millions of tons annually. Supposing that this quantity should be required, then, at that rate of demand, the coal-field would be exhausted in the course of 256 years."

Mr. Fordyce appears to concur in these calculations of Mr. Hall; for myself, I am ready to accept results which have been arrived at on independent grounds by persons so well acquainted with the district as the authors above named. My own calculations of the resources and the length of time necessary for their exhaustion is somewhat greater, arising, principally, from a smaller deduction for waste and loss than that assumed by Mr. Hall.

J.

Coal-Fields of Tyrone and Antrim.

As the work of Sir R. Griffith is not generally accessible, I here insert further details regarding the coal-fields of which it treats:

The *Tyrone Coal-field* is situated in the Barony of Dungannon, and a few miles to the west of Lough Neagh. It is of trifling extent when compared with the great Southern and Western Coal-districts of Ireland, but it is superior to them in the thickness and quality of its numerous beds of coal.

The general succession of the formations are as follows:—

1. Trias?—Red sandstones and marls, resting unconformably upon the coal-formation.
2. Coal-measures.—Alternating beds of black shale, sandstone, argillaceous ironstone, fire-clay, and coal.
3. Limestone Shale.—Consisting of sandstone, limestone, and shale with thin beds of coal.
4. Carboniferous Limestone.—Massive limestone, passing upwards into a series of alternating beds of sandstone, shale, slaty limestone with coal.
5. Old Red Sandstone.—Red sandstone, &c.

The coal-field is divided into two parts, namely, the Coal Island District, and the Annahone District.

The Coal Island District is six miles long, its average breadth is about two miles; therefore, the total extent may be about seven thousand acres.

The Annahone District is much smaller. It is one mile long, and half a mile broad. It may, therefore, contain 320 acres. Mr. Griffith states, however, that it is probable the district may extend a considerable distance further to the south and east, and that coal may be wrought from beneath the red sandstone. The coal-field is, moreover, covered to a

considerable depth with Drift deposits, which render the strata difficult of access.

The following is some account of the coal-seams in descending order:—

	Yards.	Feet.	In.
Upper Coal (impure)	0	2	2
Strata	12	1	0
Annagher Coal (soft quality)	0	9	0
Strata	18	1	0
Bone Coal	0	3	0
Strata	13	0	0
Shining Seam	0	2	10
Strata	26	0	0
Brackaveel Coal (good quality) ..	0	4	6
Strata	28	0	0
Baltiboy Coal (sulphureous)	0	3	0
Strata	24	0	0
Gortnaskea Coal {Cannel .. 2 feet / Coal .. 4 " }	0	6	0
Strata .. .. (about) ..	75	0	0
Derry Coal (good quality)	0	4	6

Below these there are two or three other seams. Most of the coals are of good quality, and have not, as yet, been worked to any great depth.

Antrim Coal-District.

The Antrim coal-district, in point of geological position, is by much the most remarkable in Ireland. It is situated on the north coast of the county, and extends to the west and south of the magnificent promontory of Fair Head from Ballycastle to Murlough Bay, a distance of four miles. Its average breadth is one mile and a half.

The general arrangement and succession of rocks which compose the coal-formation of the district, is finely exposed to view in the range of precipitous cliffs which stretches from

the Salt Pans, east of Ballycastle, to Murlough Bay. Throughout this line of coast, the coal-strata are in some places surmounted by masses of basalt, presenting towards the sea, ranges of vertical columns. In other parts, the beds are bent-faulted, and traversed by several dykes of greenstone.

A good section of the beds is visible in the cliffs near the Gob mine, exhibiting a height of strata amounting altogether to 373 feet, of which 51 feet at the summit consist of imperfectly columnar trap, and the remainder is composed of alternating beds of coal, sandstone, shale, and limestone. The main bed of coal is 4 feet thick.

The following is the section visible on the northern side of Murlough Bay from the top of the cliff downwards :—

Section in Murlough Bay.

	Feet	In.
Columnar Greenstone (about)	100	0
Brownish-red Sandstone	20	0
Bituminous Coal	1	0
Red Sandstone	80	0
Black Shale	6	0
White Mine Coal (highly bituminous) ..	2	6
Brownish-red Sandstone	40	0
Bituminous Coal	0	6
Red Sandstone	20	0
Black Shale	10	0
Bituminous Coal (Goodman's Vein)	2	6
Black Shale	60	0
Uninflammable carbonaceous Coal	2	6
Black Shale passing into flinty-shale ..	2	0
Second columnar Greenstone (basalt) ..	70	0
Black Shale	2	0
Non-flaming Coal, with thin beds of black Shale	8	6
Black Slate (base not visible)	10	0
	437	6

It appears from the foregoing section, that the coal-formation at Murlough Bay contains six beds of coal, four of which are highly bituminous, and two wholly carbonaceous, or anthracitic. The four bituminous beds all occur between the first and second basaltic ranges, and the two carbonaceous beds are nearly in contact, one above, and the other beneath the second basaltic range. The general base of the coal-formation of the Antrim coast is probably mica slate.

The early workings in the coal-mines of Ballycastle have already been alluded to.

INDEX.

THE END.

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CHARACTERISTIC FOSSILS

OF THE COAL FORMATION.

ERRATA.

1. In List of Books by same Author, facing Title-page, "Lacashire" *for* "Lancashire."
2. Page 109, foot note, "Sir J. Kay*e* Shuttleworth" *for* "Sir J. Kay Shuttleworth."
3. Page 164, last line, "corks" *instead of* "rocks."
4. Index, under Binney, "Flinthire" *for* "Flintshire."
5. Ditto "Ramsey" *for* "Ramsay."


4


5


6

1. ANTHRACOSIA ROBUSTA.
2. GONIATITES PARADOXICUS.
3. AVICULO-PECTEN PAPYRACEUS.
4. MELANIA RETICULATA.
5. LINGULA SQUAMIFORMIS.
6. SPIRORBIS CARBONARIUS.

20/3
J.W